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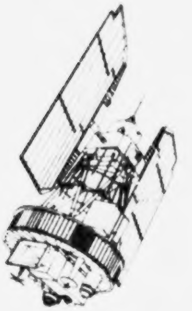

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CENTO WORKSHOP
ON
APPLICATIONS OF REMOTE SENSING DATA AND METHODS

Proceedings

Istanbul, Turkey
October 5–12, 1976

CENTO APPLICATIONS OF REMOTE SENSING DATA AND METHODS, 1976

FOREWORD

This volume presents the technical papers that were given at the Workshop on Multidisciplinary Applications of Remote Sensing Data and Methods at Istanbul, Turkey, October 5-12, 1976. It has been printed by the U.S. Geological Survey in collaboration with the Agency for International Development, U.S. Department of State, on behalf of the Economic Programme of the Central Treaty Organization, and supplements the "Report on the Workshop on Multidisciplinary Application of Remote Sensing Data and Methods, Istanbul, October 5-12, 1976," of the Advisory Group on Minerals Development Economic Programme, Central Treaty Organization (EC/25/M/D6), October 22, 1976, which presents an account of activities, without the technical papers. The latter report may be found to be of interest and value to the technical investigator because it contains questions on the technical papers and responses that were made during the sessions.

This was the fourth in a series that began in 1971 under the auspices of the Advisory Group on Mineral Development of the Central Treaty Organization. Eight Delegates and two Observers from Iran, seven Delegates from Pakistan, nine Delegates and five Observers from Turkey, two Delegates from the United Kingdom, and five Delegates from the United States participated.

The objective of these programs has been to assist CENTO country scientists to prepare to use data obtainable from the U.S. Earth Resources Technology Satellites (ERTS, now designated Landsat 1 and 2) and aerial surveying systems for analysis of environmental conditions and the monitoring of changes in them over time.

Although the workshops were developed in the Advisory Group on Minerals Development and among scientists professionally concerned with geologic exploration and analysis, they have from the first addressed not only geology, but also cartography, agriculture, forestry, rangeland industry, geohydrology, land-use mapping, geography, and coastal processes.

These programs have been supported enthusiastically by the U.S. Agency for International Development (USAID), the Ministry for Overseas Development of the United Kingdom, and by the Governments of Iran, Pakistan, and Turkey, which have expended great effort toward making them successful.

The first of the workshop series was held in Ankara, Turkey, November 10-13, 1971. Preceding the launch of Landsat 1, it was aimed at providing information that would enable scientists of Iran, Pakistan, and Turkey to develop projects to test the applicability of data about to become available from Landsat 1 and data obtainable by employment of airborne systems to problems already being studied. The proceedings of that meeting appeared in "CENTO Seminar on the Applications of

Remote Sensors in the determination of Natural Resources," published by the Office of the United States Coordinator for CENTO Affairs, Central Treaty Organization, Ankara, Turkey, August 1972.

The second program, a "Training Course on the Application of Remote Sensors in the Determination of Natural Resources," was conducted in Tehran, Iran, September 16 to October 6, 1972. The program consisted of 18 hours of general sessions in which lectures were presented on the subjects of elementary photogrammetry and basic photointerpretation; on applications of remotely sensed data in geology, hydrology, oceanography, agriculture, forestry, rangeland industry, geography, land-use analyses, and cartography; on multiband photography; and on the use of equipment for its enhancement for interpretation. Following the general session, 36 hours of individual sessions in the resources disciplines were conducted.

A field trip was made across the Elburz Mountains and along the Caspian Coast during which aspects of geology, land use, agriculture, forest industry, and watershed management were examined. In addition, a shorter field trip was made to examine the geology of the Hauz-e-Sultan. Two days were devoted to demonstration and experimentation in the use of color-additive viewing equipment, and, finally, two days were devoted to the preparation and discussion of remote-sensing projects for each of the CENTO Regional Countries. Elements of these became subjects of projects in the U.S. National Aeronautics and Space Administration (NASA) Landsat experiment programs. The proceedings of this program are reported in "Advisory Group on Minerals Development, Training Course on the Application of Remote Sensors in the Determination of Natural Resources, Geological Survey of Iran, Meydane Shah-Yed, Tehran, September 16 to October 7, 1972," released by the Central Treaty Organization, Ankara, Turkey.

The third in the series of programs was the "Workshop on the Applications of Remote Sensing Data and Methods," held at Lahore, Pakistan, March 2-8, 1975. It focused on the results of investigations by participating scientists of applications of data to areas in which they were working and for which Landsat data in the form of transparencies and prints at scales of 1:3,369,000 and 1:1,000,000 were furnished through the Multilateral Technical Cooperation Fund of CENTO. Twenty-four papers on the subject of applicability to problems of agriculture, land-use mapping, soils, forestry, hydrogeology, engineering geology, cartography, exploration geology, and changing shoreline conditions were presented by Regional Countries' delegates; overview papers on current status of applications and methods in agriculture, forestry and range industry, cartography, hydrology, geography, and geology were presented by experts from the U.S.

The presentation of formal papers was followed by 2 days of workshop sessions in major subject catagories. In addition, during the meeting week, a special presentation of talks was made to managers and technical personnel of the Water and Power Development Authority of Pakistan, and field trips were made to the Balloki Headworks and to the Daoud Hercules Fertilizer Factory. The program closed with a field trip to the Salt Range and the Khewra salt mine. This third program is reported in "Advisory Group on Minerals Development, Report of the Workshop on the Application of Remote Sensing Data and Methods," released by the Central Treaty Organization, Ankara, Turkey, April 8, 1975, and in "CENTO Workshop on the application of remote sensing data and methods at Lahore, Pakistan March 2-8, 1975," U.S. Geological Survey open-file report 77-488, 1977.

Success of these programs has been very gratifying. The experience has proven, again, that the success of applications and methods depends upon the skills, initiatives, and imagination of practicing professionals, and that, provided the opportunity, professionals will move vigorously and quickly not only to adaptation of new methods but to imaginative and innovative employment of them in their own home fields. Furthermore, benefits have spread rapidly and widely beyond the persons participating, through the establishment of remote-sensing activities in organizations they represented and, beyond their organizations, to other agencies of the respective governments, and to universities and professional societies in each of the countries.

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USE OF LANDSAT IMAGERY IN THE STUDY OF OPHIOLITES OF LASBELA AND KHUZDAR DISTRICTS OF BALUCHISTAN, PAKISTAN

By S. Ghazanfar Abbas
Geological Survey of Pakistan

ABSTRACT

The Khuzdar and Lasbela Districts, of the southern part of Baluchistan, though of great geological importance because of the presence of an ophiolitic suite, had not been investigated in detail previously because of inaccessibility. Consequently, Landsat imagery has been used to map the different layers of the ophiolitic suite that are exposed. It has been found that the lowermost layer, consisting of ultramafic rocks, is exposed in the northern corner of the area under discussion; that rocks of higher stratigraphic sequence are encountered to the south; and that pillow basalt, i.e. the layer 2 of oceanic crust, is exposed in the southern corner. The use of remote sensing data has therefore helped in the establishment of the stratigraphic sequence of ophiolites of Lasbela and thus provided a guideline for planning for mineral exploration in that area.

INTRODUCTION

The use of remote sensing techniques in geological surveys in Pakistan was first introduced in 1953 when nearly the whole of the country was aerially photographed at 1:40,000 scale. This was followed by reconnaissance geological mapping over an area of 170,000 square miles. The aerial photography and the photogeological work of the 1950's provided a sound base for initiating systematic regional and detailed geological studies in different parts of the country. The speed gained by the use of these photographs was phenomenal, and the geological work was made easier and more reliable as compared to that done on topographic map bases alone. However, the variations in scale from the photo centers to edges and differences of tone among exposures of the same rock type that resulted from changes in flight conditions sometimes made interpretations difficult and unreliable. The idea of using Landsat images, which do not have the above-mentioned drawbacks, was therefore, accepted by the Geological Survey of Pakistan (GSP) without any hesitation.

A remote sensing cell was created in the Headquarters of the GSP at Quetta in September 1975. The inaccessible areas of Baluchistan were chosen as the first target in an experiment to test the utility of Landsat images for solving geological problems. I, being a member of the CENTO Working Group on Intrusive and Volcanic Rocks and having some knowledge of rock types of the Lasbela area, was given the responsibility of mapping the mafic-ultramafic rock complex, which is gaining importance with general acceptance of the global tectonic theory.

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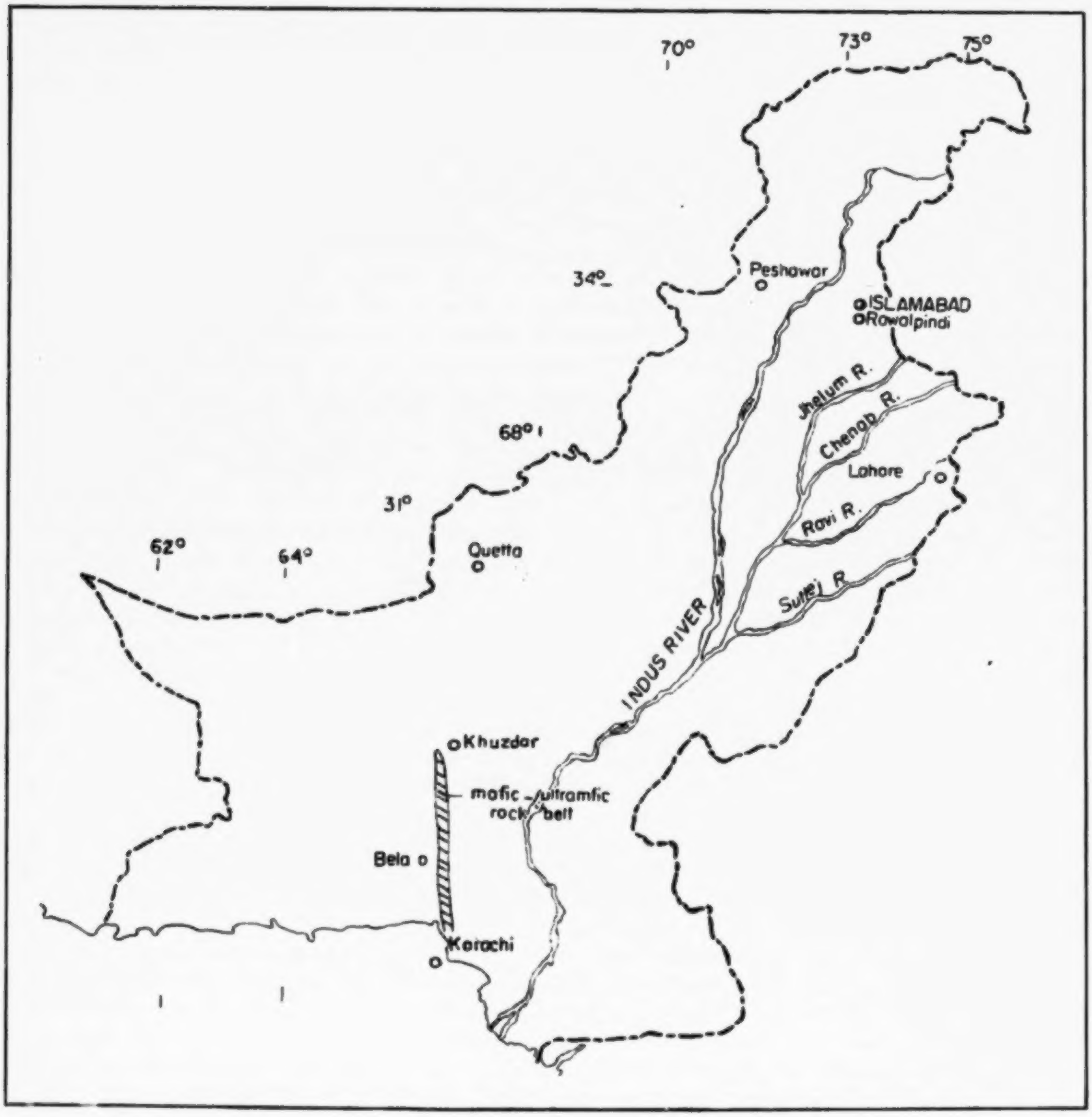

Figure 1. Index map showing location of Lasbela and Khuzdar districts, Pakistan.

When I was assigned the job, I knew nothing about the use of images, hence, Mr. M. S. Hasan, in charge of the Remote Sensing Cell in GSP, became associated with the project. He mapped the Lasbela District and gave me training. The area north of lat. 26°30' has been mapped by me and, therefore, I take full responsibility for any mistakes therein.

METHODS OF INVESTIGATION

Three image formats--70-mm positive transparencies, 9.5-inch positive transparencies, and 9.5-inch black and white prints--were used for mapping the area south of lat. 26°30' N. Color enhancements for study were created by the employment of an additive color viewer and 70-mm transparencies of multispectral scanner (MSS) bands 4, 5, and 7 images. It was found that separation of different rock types was facilitated when low-intensity red color tint was added in band 4, full intensity green color in band 5, and full intensity of blue color in band 7. Although this process is a variation from the normal practice in preparation of a color composite, it produced sharper boundaries between ultramafic rocks and the surrounding rocks. The process obscured details of the vegetation, which acquired blue tints. Cultural features were also masked. The 70-mm imagery was free of cloud cover and had been taken on November 3, 1972.

Black and white prints at 1:1,000,000 scale taken on February 8 and 9, 1975, were studied under a magnifying glass. These prints are excellent in quality and hence were put to optimum use. MSS band 5 was found to be most useful for separating different rock units. The variation in reflectances of different rock types and, to some extent, differences in morphological expression were the criteria used for mapping the area. MSS bands 6 and 7 were also studied, but it was found that the tonal differences between mafic and ultramafic rocks became obscure in these bands. Sharp rock boundaries can be seen in black and white prints with the help of a magnifying glass, but the details became masked when overlay material was applied for tracing out the geology. The final geological map is therefore not as exact as it would be if perfectly transparent material had been available.

It has been reported that mineral reflectances display sufficient variation that it is possible to identify and map rock types on Landsat imagery. However, owing to the small size of the igneous bodies and variety of rock types within the study area, a single resolution element may integrate reflectances from more than one rock type. Furthermore, data-enhancement techniques now used by the technically advanced nations were not available; hence it is not known what additional geologic information might be derived from the Landsat data. However, this new map gives a generalized idea of the rock types found in the southern axial belt of this region of Pakistan that heretofore was little known geologically.

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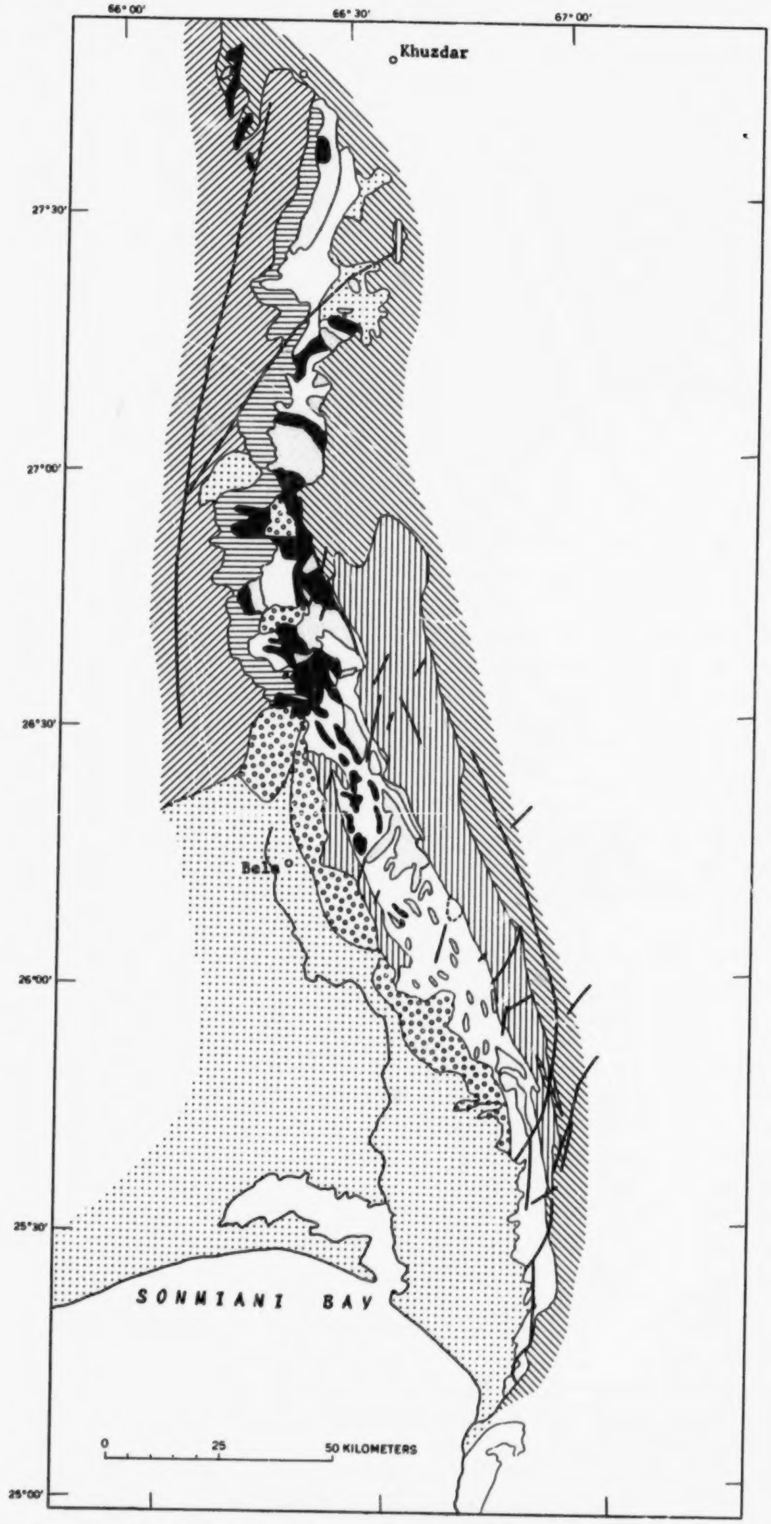

Figure 2. Ultramafic and mafic complex of part of Lasbela and Khuzdar Districts, Pakistan.

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EXPLANATION

	Formation	Lithology	Group
░	**Alluvium**	Sand and Silt	RECENT
▒	**Sub Recent**	Gravel, Sand and Silt	SUB RECENT
▨	**Hinzlaj Group**	Mainly sandstone with subordinate clayey shale and shaly limestone. The sandstone is gray to pale yellowish brown and weathers earthy-brown, dark yellow-brown. It is salt and pepper protoquartzite, soft and crumbly. Beds are well laminated to massive. The clayey shale, mudstone and siltstone are sandy and soft, thin bedded and at places gypsiferous.	MIO-PLIOCENE
▤	**Nal Limestone**	Predominant limestone with subordinate sandstone and shale and minor conglomerate. The limestone is light gray on fresh surface and weathers yellow brown, dark brown, rusty brown, pinkish buff, and light-gray. It is thin to thick bedded and contains abundant fossils. The sandstone is green-gray to pale yellowish brown and weathers earth brown, dark yellow-brown, rusty, and maroon. It is medium bedded, commonly micaceous, poorly sorted and has a salt-and-pepper texture. Well-cemented and well sorted varities are also present in minor amounts. The shale is soft, silty, clayey, or sandy and weathers earthy brown or green-gray. Lateritic red and earthy yellow, earthy shale is locally common. The conglomerate contains angular to well rounded pebbles of igneous rocks that include serpentine and diorite and sedimentary rocks that include chert, gray limestone and Pab Sandstone.	OLIGO-MIOCENE
☐	**Bela Volcanics**	Lava interlayered with sedimentary rocks. Lava is basaltic with well developed pillow structure, grayish green, olive or greenish gray cryptocrystalline. Sedimentary rocks include limestone and shale. Limestone is cream, lightgreen; weathers to yellowish brown, thin to medium bedded. Shale is green, buff, orange, blue gray, ferruginous, brown or black.	CRETACEOUS
☐	**Bela Mafic Complex**	Basalt interlayered with agglomerate and sill-like bodies of gabbro. Basalt is dark greyish green, olive greenish gray or dark gray on fresh surface and rusty brown or greenish gray on weathered surface, cryptocrystalline with feldspar laths and some olivine/pyroxene crystals. Agglomerate consists of sub-angular to sub-rounded fragments of porphyritic volcanic rock in a basaltic matrix. Gabbro is in the form of sill-like bodies. It is equigranular, holocrystalline, medium to coarse-grained; felsic and mafic ratios are 30:60 to 60:30.	
■	**Forali Ultramatic Complex**	Discontinuous peridotite bodies, highly serpentinized, greenish black, coarse grained; olivine predominant-more than 85 %-with accessory chromite; rarely shows layering; with xenoliths of recrystallized limestone. Contact is discordant or faulted.	
▧	**Parh Group**	Shale, marl and limestone. Shale is gray, light green, olive-brown, maroon and black on fresh surface and weathers to brown shades of these colors. It is calcareous, hard, flaky, or earthy. Contains small pellets or nodules of glauconite. Marl is yellow, red, or green; its weathered surface is characteristically nodular. Limestone is pure white, light gray, pink, green, and red. It is typically porcellaneous or sublithographic and breaks with subconchoidal fracture. The beds are characteristically regular, smooth-faced and tabular; ranging from 4 inches to 2 feet in thickness.	
▥	**Winder Group**	Limestone with subordinate interbedded shale and few sandstone beds. Limestone is dark gray to black on fresh surface; weathers to light brown and blue-gray; hard, compact; beds variable in thickness from few inches to few feet. Shale is light earthy brown, ferruginous brown, earthy, blue-gray gray and black; weathers to light brown, blue gray, and rusty brown; hard, splintery and calcereous; sandstone is light brown, reddish brown or white; weathers to dirty white, pink or cream or light rusty brown; very hard and compact; beds range in thickness from 2 to 6 feet.	JURASSIC

——— **Fault**

– – – – **Possible fault**

Oval shaped body of Porphyritic Basalt

PREVIOUS WORK

The occurrence of intrusive and volcanic rocks in the Lasbela-Khuzdar region was first reported in 1909, by Vredenburg of the Geological Survey of India (GSI), who correlated these rocks with trap rocks of India. No serious attempt was made by GSI or by GSP to map the area until 1953, first, because of local political problems, and second, because the importance of these rocks to the analysis of geodynamic processes of the region was not generally recognized. In 1953, geological mapping on aerial photographs was started, with ground checks where possible. The work was made possible under a Colombo Plan cooperative project, in which technical and financial help were provided by the Canadian Government. On the completion of the project, a voluminous report of 550 pages, including geological maps of 170,000 square miles was published in 1960, at the scale of 1 inch: 4 miles. As a result of their geological studies, the Canadian geologists concluded that intrusive and volcanic rocks of the area were related to igneous activity which occurred within the eugeosyncline at different stages of its development. The rocks were therefore considered to be autochthonous and similar to rock assemblages in modern island-arc systems (Hunting Survey Corp., p. 34 and 80). Gansser, in 1974, came out with the idea that the Bela mafic and ultramafic complexes are Colored Melanges and that they were emplaced as olistostromes.

PRESENT WORK

The present work was started in late 1975 with the objective of mapping the broad units of the ophiolitic suite of rocks, to understand their genesis, and to delineate the areas favorable for different types of mineralization. The southern part of the area lying in Lasbela District, which is to some extent accessible, was mapped using Landsat data in the laboratory. The map thus prepared was checked in the field and was found to be reasonably accurate. The knowledge thus gained was extended to the northern part, the Khuzdar District, which is still inaccessible for geological work.

It has been possible in the course of this work to divide rocks formerly grouped and mapped as Porali intrusives and Bela volcanics into ultramafics, gabbroic intrusives, and pillow basalt with a description of the rock units is given as Figure 2 of this paper. The present work shows that large blocks of serpentinized dunite and peridotite occur mostly at the northern end of the mapped area. Major gabbroic bodies occupy the central portion; and basaltic pillow lava interlayered with sedimentary rocks occupies the southern end of the igneous complex. However, this is a very broad generalization; on detailed observation, smaller bodies of gabbroic and volcanic rocks are found along with larger ultramafic bodies, and vice versa. Ultramafic rocks cropout in fault contact with older sedimentary rocks and appear similar to other ultramafic masses emplaced tectonically from the mantle. The volcanic rocks are basaltic in composition and contain sedimentary interlayers of limestone, marl, shale, and radiolarian chert; these can therefore be correlated with oceanic crust rock. Therefore, it appears from the present work that mafic and ultramafic rocks of the southern part of Baluchistan are not a Colored Melange in a real sense but represent small blocks of oceanic crust and mantle material. These rocks have been emplaced along the axial belt in conjunction with the collision of the Indian with some oceanic plate. However, detailed petrological, geochemical, and geophysical work will be needed to prove or disprove the above hypothesis.

In regard to the economic aspect of the work, our broad definition of the geological environment of the area suggests that we should look for the sulphide ores of copper, zinc, and lead, and oxides of manganese and iron in the southern part of the area, and search for chromite, platinum, and nickel ores in the northern part.

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APPLICATION OF LANDSAT IMAGERY
TO PETROLEUM PROSPECTING
OF A PART OF IRAN

By S. Agah

Exploration & Production
National Iranian Oil Co.

INTRODUCTION

Landsat images have been used in the National Iranian Oil Company, Exploration and Production, ever since they became available in Iran, principally for illustration of regional geological reports, and compilation and correction of the new 1:1,000,000 Geological Map of Iran, which will be published during the current year.

Because of their synoptic view of large areas, particularly regions difficult of access, and the similarity of their scale to the scales of maps to be prepared, these images were utilized directly as the base on which to outline major tectonic elements (mainly lineaments) and certain feature-forming rock units in some parts of the country.

In addition, recent analysis of the Landsat data has shown that in certain areas of hydrocarbon potential, some regional structural features had escaped the attention of geologists and therefore do not appear on any map. This is probably due to the fact that individual aerial photographs (approximate scale 1:50,000) provide information of segments only of the total photographed area, and photomosaics, because of tone and scale variations among component photographs, do not provide the desired uniform synoptic view that is obtained by Landsat.

During the 1976 field season, the writer visited and surveyed parts of two regions in Iran, where previously unknown large-scale lineaments (fracture and faults) that appear in Landsat images are now proven to exist. These tectonic elements, which seem to have a direct effect on the petroleum prospects of these localities, were discovered on the satellite images and checked in the field.

The geological setting of one of these areas is discussed briefly in the following paragraphs.

NORTHWEST DARAB AREA

The northwest Darab area of interior Fars, ($53^{\circ}30'$-55°E; $28^{\circ}30'$-30°N), south Iran (fig. 1), is characterized by mountain-forming (more than 3000 m), mainly warped, massive limestone of Eocene (Jahrum Formation) and Maestrichtian (Tarbur Formation) age and a substratum of incompetent, thin-bedded chert and siliceous limestone of the post-Turonian-pre-Maestrichtian Radiolarite Groups that is exposed in the floor of deeply cut gorges. The area lies directly between the zone of extreme tectonic disturbance at the northeast (Zagros thrust and ? Nappes) and the regularly folded belt of Zagros structures at the west and southwest. In the latter direction the pelagic radiolarites are abruptly replaced by marl and argillaceous limestone of the Gurpi Formation (Campanian), which are considered as both the source of hydrocarbons found in the overlying Tarbur Formation and the cap rock for the underlying reservoir limestones of the Sarvak Formation of Cenomanian age.

Nearly 70 km northwest of Darab (fig. 1), the Kuh-e-Tudej anticline, exposing Tarbur limestone in its core and measuring approximately 65 km in length and 20 km in width, has long been regarded as one of the largest and most favorable structures in this part of Iran for testing all reservoir formations from the Sarvak down to the Permian limestones of the Kangan Formation.

Knowing that the structure was positioned near the northeastern edge of the Zagros fold belt, where extensive exposures of the radiolarites had been mapped, it was important to field-check the areal extent of the latter rock unit to ascertain that these abyssal limestones and chert beds are not present in the Tudej anticline, the reasons being that (a) very little, if anything, is known about the stratigraphic succession below the radiolarites, and (b) to judge the shallow Sarvak horizon favorable for a test for oil, it is essential to verify the presence of the Gurpi cap rock, which in this area interdigitates with the radiolarites along a northwest-southeast strike (fig. 2).

Soon after the survey had started, and prior to investigation of the Landsat data, a small outcrop of radiolarites, below the Tarbur Formation, was found in a locality just east of the eastern end (plunge) of the structure. This discovery was discouraging with regard to the petroleum prospects of the Tudej anticline.

Referring to a Landsat-1 image (fig. 3), we noticed a lineament trending approximately N.15°W. (fig. 2), which seemed to cut through the broad eastern end of the Tudej structure, extending east of Neyriz (Bakhtegan) Lake, and eventually joining up with a major dextral transcurrent fault in south-central Iran (Deh Shir Fault). This feature had

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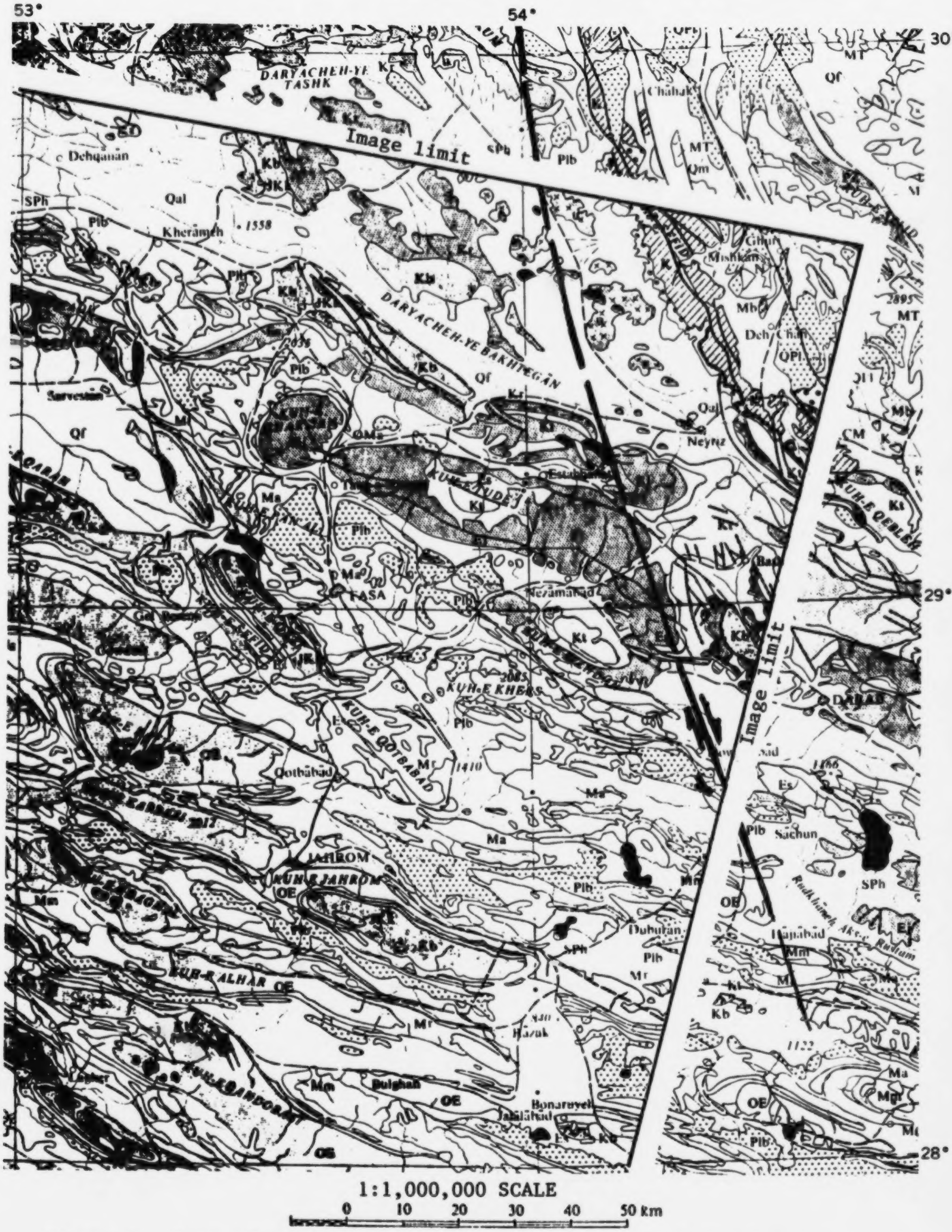

Figure 1. Part of geological map of Iran showing the Fars area and the position of a northwest-trending strong lineament discovered on Landsat image 1149-06291.

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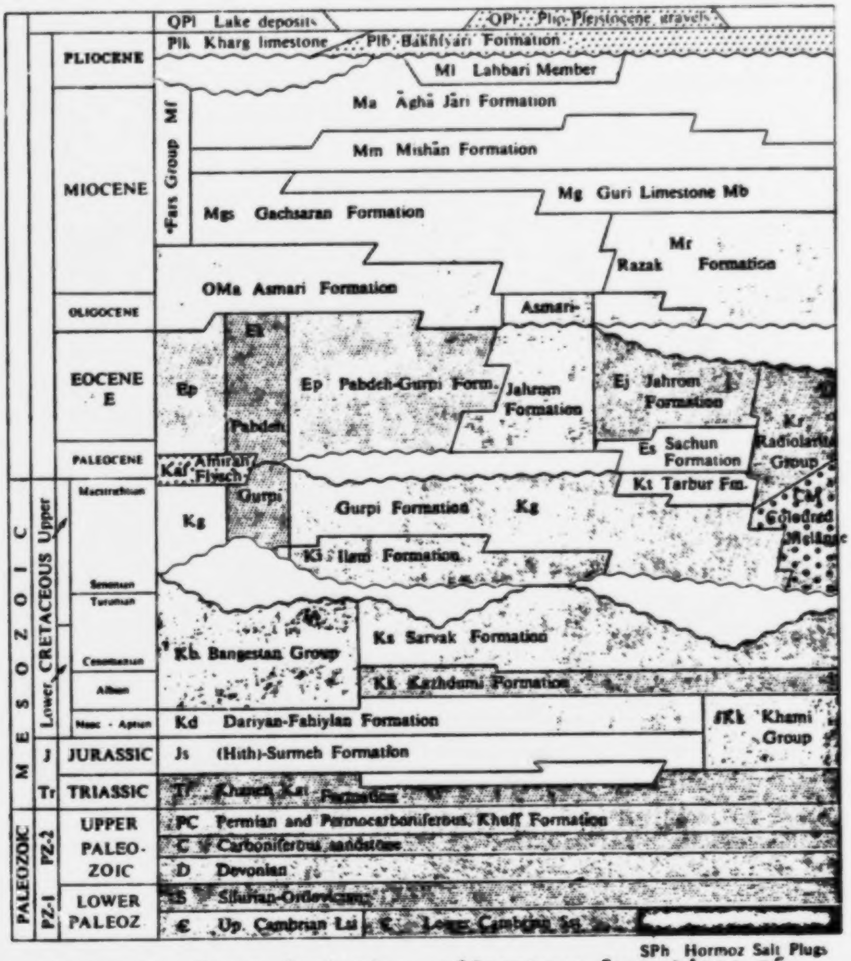

Figure 2. Chart depicting sedimentary formations of southwestern Iran.

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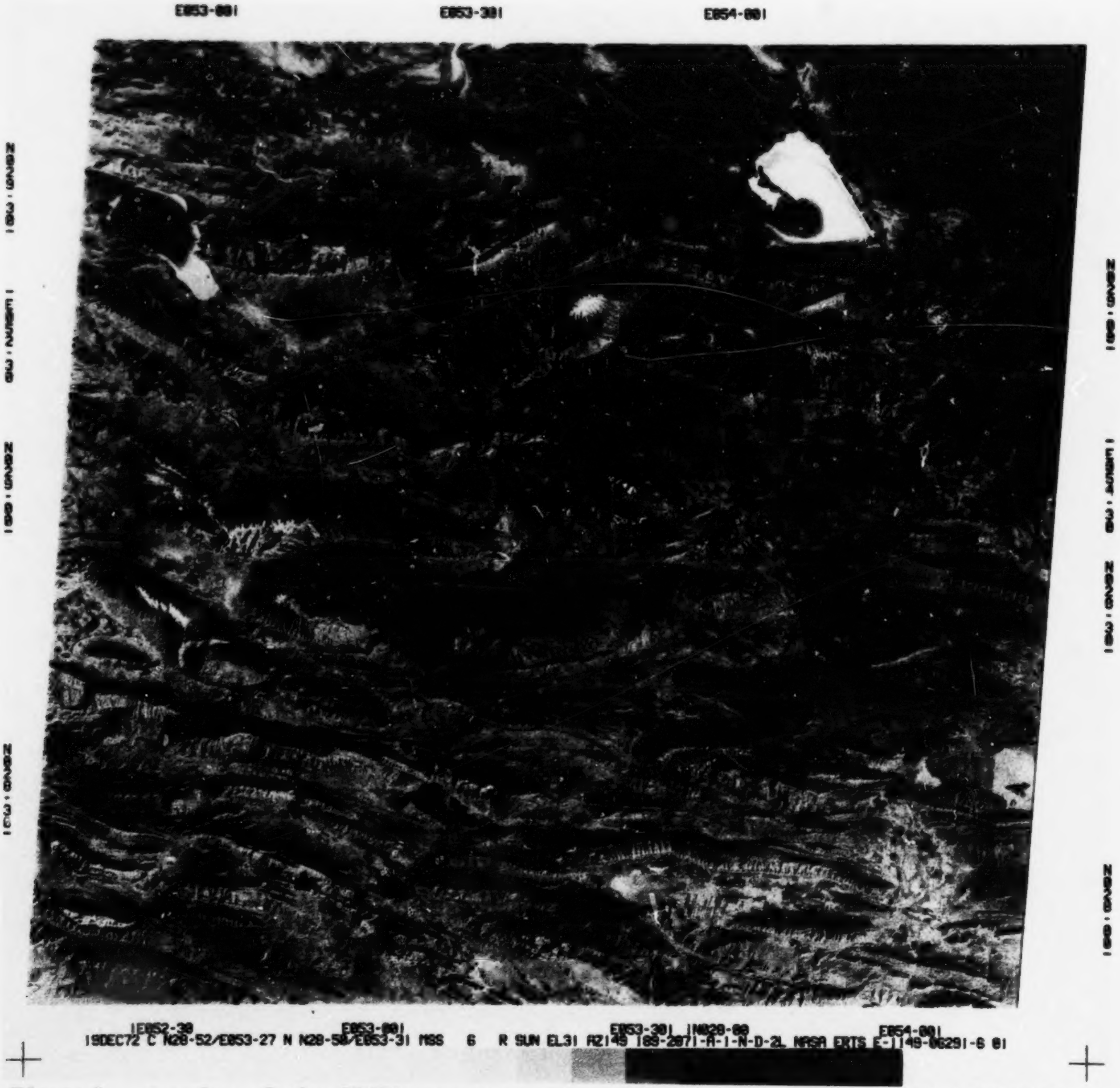

Figure 3. Results of the CENTO remote sensing workshops program included detection of a geologic lineament separating platformal and abyssal sedimentary formations in the Kuh-e-Tudej anticline and aided in the direction of field work and the location of an exploratory test for oil and gas (S. Agah, Iranian Natl. Oil Co., 1978).

not been mapped before. The image (1149-06291) was acquired by Landsat-1 on December 19, 1972, and covers the entire length of Kuh-e-Tudej, together with the total region of Darab-Neyriz-Shiraz. A black and white print, band 6, at the scale of 1:1,000,000 was used for analysis.

Going back to the field, the party found several other radiolarite exposures on the east side of the fracture, but none west of it.

Looking further into deeply eroded structures in the vicinity of Kuh-e-Tudej, we were convinced that the marine Gurpi Formation is developed west of this newly discovered lineament, whereas east of it, age-equivalent radiolarites predominate, and the two rock units tend to interfinger sharply along its north-northwest trend. This line may, therefore, be interpreted as demarking the eastern edge of a Late Cretaceous continental platform, on which marls and argillaceous limestones of the Gurpi were laid down in relatively shallow waters. Farther east and northeast of it, radiolarites were deposited on the continental slope and abyssal plain in extremely deep waters.

Since the Tudej anticline is located west of the newly discovered line, we may now be certain of penetrating a normal platform succession once drilling of the first Tudej exploratory well is commenced.

APPLICABILITY OF AERIAL MULTISPECTRAL PHOTOGRAPHIC TECHNIQUES TO STUDY OF THE HYDROGEOLOGY OF THE DALAMAN STREAMLET AND ITS ENVIRONS

By Dr. Nihal Atuk
Geotechnical Services and Groundwater Department
State Waterworks (DSI) of Turkey

INTRODUCTION

The purpose of the studies to be reported here has been to examine the hydrogeology and engineering characteristics of the Dalaman basin and its environs in southwestern Turkey. Methods employed included those of aerial panchromatic photographic surveys, field studies, geophysical surveys, and drilling, that had become standard, and the more recently developed "remote sensing" methods of Landsat, aerial multispectral photography, and additive color viewing.

GENERAL HYDROGEOLOGIC CONDITIONS OF THE STUDY AREA

The Dalaman streamlet is situated in the southwest of Turkey, in an area roughly 90 km east of Muğla. The Mediterranean climate prevails in the investigation area. Winters are cool and rainy; summers are warm and dry. Precipitation is in the form of rain, and annual mean precipitation is 1131.3 mm.

The Dalaman State Paper Mill and State Farm for stock breeding and agriculture are located in the investigation area. Water for drinking, domestic use, and irrigation in this area is supplied from the Dalaman streamlet and from wells drilled in the alluvium.

Formations in the study area are Quaternary and Neogene alluvium of clay, sand, and gravel, Neogene limestone, conglomerate, sandstone, and marl, and Cretaceous limestone, serpentinite, and peridotite.

Alluvium, the only dependable aquifer, contains abundant groundwater. Its thickness reaches 100 m in some places. Annual safe yield in the study area is 8.8×10^6 m^3/year. The groundwater is suitable for drinking, domestic use, and irrigation; however, the waters of some springs in the area are rich in sulphur and therefore are not suitable for these purposes.

HYDROGEOLOGICAL STUDIES EMPLOYING REMOTE SENSING TECHNIQUES

Remote sensing techniques employed included Landsat imagery analysis and black and white panchromatic and multispectral aerial photography. Additive color viewing has been employed in analysis of the multiband Landsat and aerial camera data.

Landsat imagery has been analyzed both with aid of the additive color viewer, employing black-and-white film positives of band 4 (green), band 5 (red), and bands 6 and 7 (both infrared) at the original scale of 1:3,369,000, and by visual analysis of false-color infrared composite imagery at the scale of 1:500,000. Although the Landsat imagery was found inadequate for the solution of detailed hydrogeological problems because of the small scale, it was found to be very useful for determining the presence of great faults, of areas of plains, cultivation, lithologic variations, and alluvial cones. The comprehensive view of the study area contributed greatly to the understanding of relationships among terrain elements and the hydrogeological conditions of the study area.

Subsequent to the study of Landsat data, investigation turned to aerial multispectral photography at the scale of 1:20,000. Optical analyses were made of the individual blue, green, red, and infrared band 5 black and white photographs, without the aid of equipment, and also by composing them into color views on the screen of the additive color viewer.

The aerial multispectral photography was obtained at several seasons. Samples of water of the Dalaman streamlet, wells, lakes, and the coastal water of the Mediterranean for analysis of chemical and sediment contents were taken at the time that the aerial surveys were being made. The density distributions within the multiband photographs were measured and mapped by densitometry. It was found that boundaries could be readily drawn between areas of fresh water and brackish water, and brackish water and sea water in the vicinity of the mouth of the Dalaman.

In the case of Sülüngür Lake, a coastal lake the water of which is normally comparable to that of the sea, analysis of the multispectral aerial photography acquired at the time of heavy May rainfall showed that the area of fresh flood water in the lake could be delineated. Furthermore, it was observed that wind-induced waves did not adversely affect the camera's capability to record color variations of the water.

The multispectral aerial photography revealed the effects on groundwater and on forest cover of the contamined water that is discharged by the Dalaman Paper Mill. Places of entry into the Dalaman of sulphurous spring waters and the distributions of water of varied qualities were clearly discernible, as were talwegs, the courses of buried river beds and buried stream channels. Variations of depth in the shallow Lake İztuzu were readily recognizable.

CONCLUSIONS

Periodic observations, employing aerial photographs and data obtained by earth satellite-borne cameras and scanners provide information relative to water-plant-soil-temperature relationships, which when combined with supporting field and laboratory studies is most useful for the resolution of hydrogeological problems.

Field studies, geophysical surveys, drilling activities, and various remote-sensing techniques are concluded to be complementary elements in hydrogeological investigations.

It is believed further that significant contributions to the solution of detailed hydrologic problems will be made using low-altitude airborne scanner data both in minicomputer processes and in visual interpretation aided by stereoscope, additive color viewer, or similar instruments.

REMOTE SENSING TECHNIQUE

FOR THE

SOLUTION OF FLOOD PROBLEMS IN PUNJAB,

PAKISTAN

By S. M. Ayoob
Secretary, Irrigation and Power Department
Punjab, Pakistan

INTRODUCTION

The word "Punjab" is a Persian word meaning "five wat[illegible]is plain comprises the valley plains of five rivers, namely, the Jhelum, the Chenab, the Ravi, the Beas, and the Sutlej. These rivers are the tributaries of the mighty Indus River. The main Indus rises in Tibet and traverses a long tortuous mountain course before it enters the Punjab plain at Kalabagh. All its tributaries originate in the snow-clad Himalayas, pass through India or Jammu-Kashmir State (disputed territory), and join River Indus at Mithankot, Punjab, which is 342 miles below Kalabagh (figure 1).

The Punjab plain forms a vast tract of about 71,000 square miles, having a total length of about 450 miles and a total width of about 250 miles. This plain is 600 to 1200 feet above mean sea level which is reached at the mouth of the Indus at Karachi. The general slope of the plain varies from 2 feet to 1 foot to the mile from north to south. The region is occupied by a great mass of alluvium brought down by the Indus and its tributaries over ages of time. The thickness of alluvium deposited in the basin is of the order of 6000 feet. It is the alluvial nature of the soil which is mainly responsible for the meandering of the rivers and consequently for river erosion.

CAUSES OF FLOODS IN THE PUNJAB RIVERS

Rainfall--The main cause of floods is the heavy rainfall in the submountain catchment areas of the Punjab rivers. The widespread rainfall results from the passage of the tropical atmospheric depressions that are formed in the Bay of Bengal during the monsoon and which, while travelling over Rajistan, India, are revived by fresh incursions from the Arabian sea and finally dissipate in the hills of southern Kashmir. The most devastating floods of 1950, 1955, 1957, 1959, 1975, and 1976 were the result of such heavy monsoon rainfalls.

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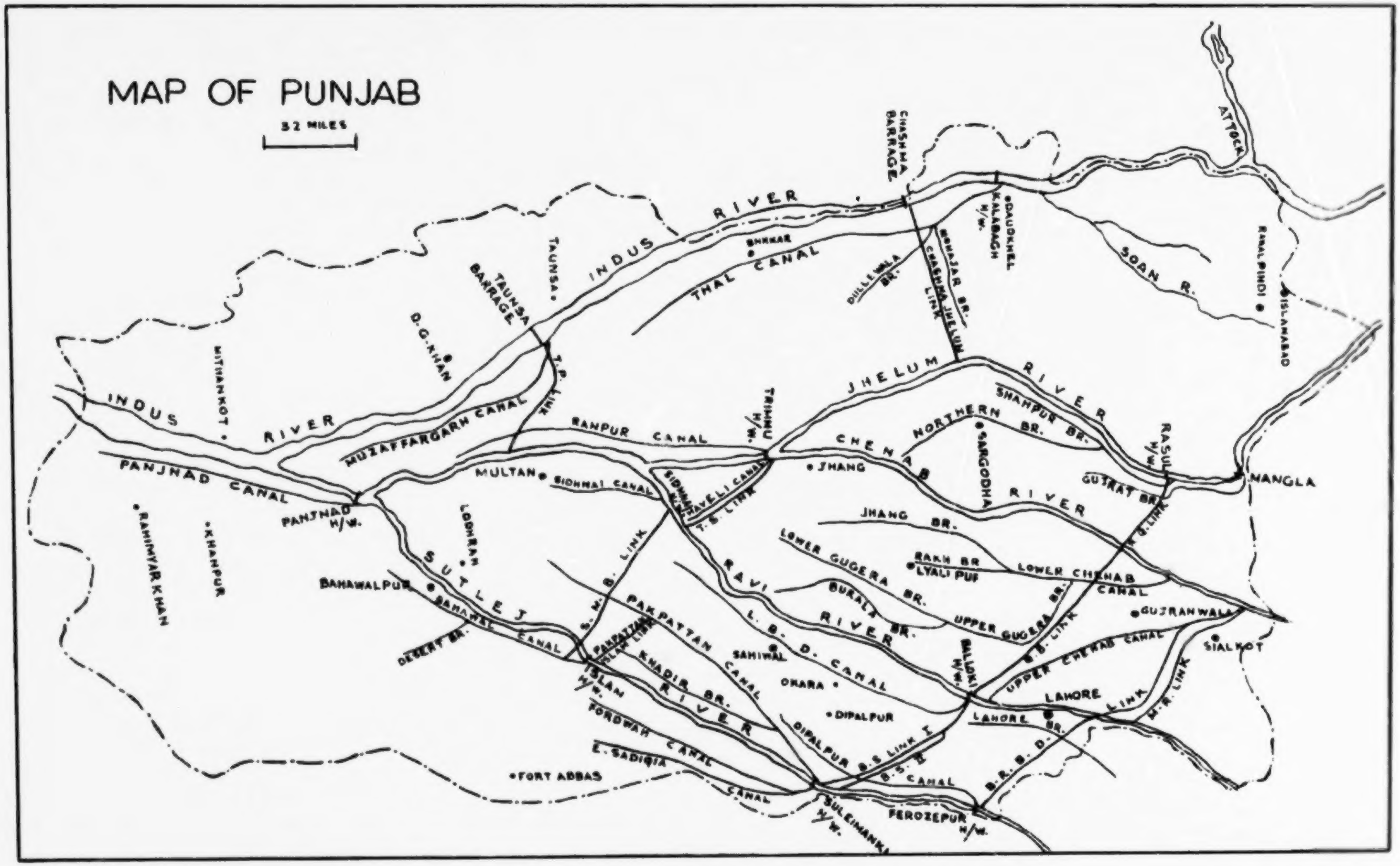

Figure 1. Map of Punjab plain showing rivers and waterways.

The flood of 1976 was unprecedented in its nature. The devastations suffered during this flood were not only due to the superflood flows in the rivers, but were largely due to the intensive and extensive rainfall that fell over northern Punjab continuously for 2 weeks, affecting 9.4 million acres and resulting in heavy damage to crops, irrigation channels, roads, and rail and flood embankments. The mud houses were worst affected and their collapse resulted in casualties. The canal, road, and rail embankments had to be cut at many places to allow for draining off the water from heavily flooded villages, towns, and cropland areas.

The rainfall at some of the important sites and damages/losses measured during 1976 and at times of other superfloods are attached as Annex I and II.

DETERIORATION, DENUNDATION, AND EROSION

The removal of the forest cover from the catchment areas increases the rate of runoff and aids in creating flood conditions. Pakistan is helpless to stop this process as most hilly catchment areas lie beyond Pakistan territory.

The process of heavy erosion on the slopes of hills which are devoid of forest cover causes the transportation of millions tons of detritus, which is deposited in the beds of rivers. Thus the beds of rivers are rising year by year, which leads to greater flood heights in the Punjab rivers.

SHAPE, SIZE, AND SLOPE OF THE CATCHMENT

Shape and size of the catchment--The shape and size of the catchment area of a river plays an important role in the disposal of precipitation through various torrents and streams, into the river. The runoff from square or circular catchments like those of the rivers Ravi, Sutlej, and Chenab results in sudden floods. Because the catchment area of the River Indus is oblong in shape, the flood flows are spread over a longer period, with gradual rises from flood discharges.

Slope--The slope of the catchment and the river basin is another important factor that controls the discharge, carrying capacity, valley storage, velocities, and flood heights of a particular river. A brief description of slopes of the Punjab rivers is given below:

River/Reach	Average fall per mile in hilly reach (in feet)	Slope per mile in plain area (in feet)
a. Sutlej		
From source (Mansarowar) to Rupar (hill reach), distance 442 miles.	49	-
Rupar to Panjnad (plain), distance 423 miles.	-	1.7 to 0.9
b. Ravi		
From source (Bangahal) to Madhopur (hilly reach), distance 110 miles	160	
Madhopur to confluence with Chenab (plain), distance 450 miles		6.0 to 1.0
c. Chenab		
From source (Chandra) to Marala (hilly reach), distance 374 miles	54	
Marala to its confluence with Indus (plain), distance 398 miles		3.0 to 0.9
d. Jhelum		
From source to Mangla (hilly reach), distance 300 miles	43	
Mangla to confluence Trimmu (plain), distance 192 miles		5.0 to 1.2
e. Indus		
From source to Kalabagh (hilly reach)	46	
Kalabagh to sea near Karachi (plain), distance 970 miles		2.0 to 0.3

From the above, it is apparent that practically all the rivers have very steep slopes in their hilly catchments; consequently the floods enter the plain with gushing velocities. The slopes of the rivers in Pakistan range on the average from 3 feet/mile to 0.5 foot/mile as they travel from the submountainous regions to the plains. The steep slopes of the rivers in the hilly catchments are mainly responsible for the erosion and the transportation of sediments from the hills to the plain. These ultimately are deposited in the river beds. Such deposits in the beds of the rivers induce meandering and lead to flood hazards.

ARTIFICIAL BARRIERS CONSTRUCTED ACROSS THE RIVER

Many barrages, bridges, and syphons have been constructed for the development of the country. The nation, however, pays for these artificial obstructions by suffering the deterioration of river regimes, the accretion of sediments, meandering and, ultimately, higher flood levels. The detail of works constructed across these rivers is given below:

No.	River	Headworks	Syphons	Road bridges	Railway bridges	Total
1.	Sutlej	2	1	1	1	5
2.	Ravi	2	1	4	3	10
3.	Chenab	5	-	4	4	13
4.	Jhelum	1	-	1	3	5
5.	Indus	6	-	2	5	13

CONSTRUCTION OF DAMS AND RESERVOIRS

India has constructed dams and diverted waters of the three eastern rivers, namely, Sutlej, Beas, and Ravi. This has seriously disturbed the natural regime of these rivers in Pakistan.

Pakistan has also constructed two dams, the Mangla on the Jhelum and Tarbela on the Indus. Tarbela was completed last year (1975); and its effects on the regime of the river will appear only after some years. The Mangla Dam has begun to have its effects on the river regime in that the deterioration of the river's channels has resulted in higher flood heights.

ENCROACHMENT ON FLOOD PLAIN

The population of Pakistan is on the increase and to meet the increasing demand for food and fibre, the areas in the flood plains along the rivers are being gradually brought under cultivation. At many places, cultivation/canal irrigation has been extended up to the river edge.

OBSTRUCTION AGAINST THE NATURAL DRAINAGE

Many works, rail, road and canal embankments and expecially, "Link Canals" for transferring waters from the western rivers to the eastern rivers have been constructed across the drainage lines, out of sheer necessity. These have blocked the natural passages for the flow of rain and flood waters.

FLOOD CONTROL AND FLOOD PROTECTION MEASURES

The Indus and its tributaries are slow and sluggish when they carry low discharges and their flow remains limited to a few hundred feet in width. But in the season of snow melt and rain (April-September) they become torrential and very active. River Indus spreads over a width of about 12 miles and presents flood hazards to the areas adjacent to its course. Similarly, all its tributaries when in spate spread over large areas causing huge devastation.

The discharges of these rivers during summer and winter seasons vary greatly and the variation may range up to 200 times.

The following table shows some salient data of River Indus and its major tributaries:

S.No	Name of River	Catchment area in the mountains(sq.miles)	Approx: total length (miles)	Recorded peak disch: (million cfs)	Site of peak discharge	Year
1.	Indus Main	118400	1958	0.95	Kalabagh	1942
2.	Jhelum	12445	528	1.10	Mangla	1929
3.	Chenab	11399	807	1.10	Marala	1957
4.	Ravi	3562	626	0.54	Shahdara	1955
5.	Sutlej	*30550	964	0.49	Suleimanki	1955

*Includes the hilly catchment of the Beas River also.

The construction of storage dams as a flood control measure can not be adopted because, unfortunately, suitable sites for such works are not available in Pakistan. Only such flood protective measures as the construction of flood embankments are possible. There are 1300 miles of flood embankments in Punjab alone for providing protection to irrigated areas, irrigation channels, lines of communication, and towns. At barrages, bridges, and other vulnerable sites, river training works in the form of spurs of various shapes have been constructed.

FLOOD FORECASTING AND WARNING

As the upper catchments of the Punjab rivers lie outside Pakistan, the obtaining of advance and timely information regarding the amount of precipitation and quantity of discharge is not possible; and generally the people in the north are caught unaware and suffer tremendous loss of life and property. The technique of remote sensing can be very helpful for providing accurate and timely information about the quantity of rainfall in the catchments of rivers and the resulting runoff expected in the various rivers of upper Punjab Province. The remote sensing system can also be helpful in formulating flood protection measures and drainage projects, to avoid damage to crops and property.

It is felt that the experts on the technique of remote sensing will come forward from the developed countries to help in solving the flood problems confronting Pakistan.

ANNEX I

Statement showing monthly rainfall recorded at various stations, in milimeters/inches

Name of station	May	June	July	August
Sialkot	30.0 1.18	57.6 2.27	240.5 9.50	886.3 34.89
Lahore	20.3 0.80	83.2 3.28	270.2 10.67	517.0 20.35
Sargodha	15.3 0.60	40.6 1.60	151.6 5.97	351.2 13.83
Jhelum	15.0 0.59	30.7 1.21	184.0 7.24	545.9 21.49
Islamabad	3.0 0.12	33.3 1.31	366.9 14.48	442.5 17.42
Bahawalpur	Traces	193.2 7.61	35.7 1.40	14.2 .05

ANNEX II

Damages to Private Property by Floods/Rains in Different years

Description	1950	1955	1957	1959	1973	1976
No. of villages affected.	11,100	10,358	6,798	3,903	6,672	9,410
No. of persons lost or injured.	2,910	959	99	88	422	645
Area affected (in million acres)	4.5	5.12	4.0	3.01	8.50	9.38
Cropped area affected (million acres)	2.50	9.22	4.72	3.45	1.35	1.86
Houses damaged or demolished.	436,439	332,678	142,911	163,607	661,676	906,450
No. of cattle missing/ perished.	41,662	36,985	4,050	6,064	52,959	25,883
Food grain in million mods.	1.43	1.43	.24	2.28	4.11	3.2
Dry fodder destroyed in million monds.	3.52	1.79	1.13	1.76	11.83	1.95

MEASURING GROUND ELECTRICAL PROPERTIES BY REMOTE SENSING

A LITERATURE SURVEY

By Dr. Ali. A. Beihaghi

Ministry of Science and Higher Education
Tehran, Iran

ABSTRACT

In this survey it is shown that electric pulses containing audio and radio frequency components can be utilized in measuring the conductivity (σ) and the dielectric constant (K or E) of the ground by remote sensing. This method has been developed into an operational system for mineral exploration and prospecting. The extension of this method using VHF frequencies and a high-resolution radar technique can provide information on the moisture content of the top few feet of soil, together with its layering characteristics.

INTRODUCTION

The problem of measuring ground properties by remote sensing is receiving a great deal of attention since the orbiting of earth resources satellites. In particular, in the field of mineral exploration, airborne electromagnetic equipment and methods have been developed for use in prospecting. A method explained here is the measurement of the transient response of the ground to electrical pulses of micro- or millisecond duration. The ground properties that can be measured include conductivity (σ), the dielectric constant (K or E), and polarizability (Θ). The above parameters are very important in providing information on the possible presence of mineral deposits, on the salinity and freshness of water and ice, on the presence of soil moisture, and on characteristics of soil layers.

AUDIO FREQUENCY PULSES FOR GROUND CONDUCTIVITY MEASUREMENT

It is known that at audio and low radio frequencies, the image of an electromagnetic antenna that is reflected from a surface is primarily controlled by the conductivity of the material. Similarly, when the propagation of electromagnetic waves over the earth is considered, the wave tilt and elliptical polarization of the wave are determined by the ground conductivity at low frequencies, and by the dielectric constant at high frequencies. These are shown in figure 1. These curves indicate

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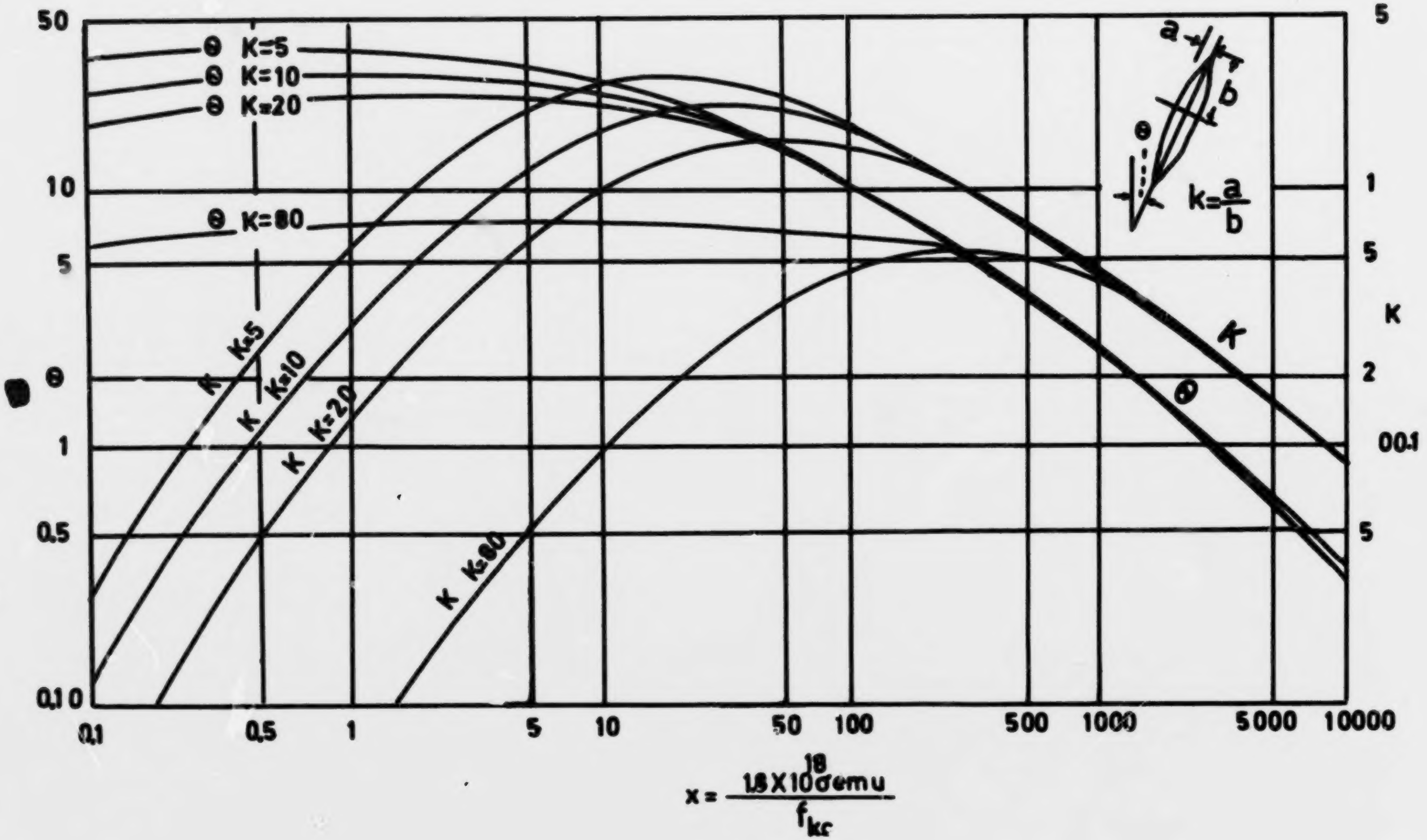

Figure 1. Characteristics of wave tilt for different values of dielectric constant K and ground conductivity factor X.

that at frequencies below 100 KHZ, the dielectric constant has very little effect on the ground wave. Above 180 MHZ the conductivity has a negligible effect on wave tilt and ellipticity of polarization. It therefore becomes clear that methods can be devised for measuring ground conductivity and dielectric constant remotely by measuring the response of the ground to electromagnetic radiation at suitably chosen frequencies. Unfortunately, difficulties arise because of the fact that conductivity measurements can only be made at relatively low frequencies which provide for high penetration, but with low resolution, whereas dielectric constant measurement requires the use of high frequencies which provide for good resolution but poor penetration. The use of intermediate frequencies, such as a broadcast band, which seems to be a compromise, gives penetration of as much as 15 meters, but creates severe interpretation problems due to the superimposition of displacement and conduction current effects.

A better compromise is to use pulses of 1.5 millisecond duration. These pulses contain frequency components that are essentially between 30 and 10,000 HZ, with energy concentration at frequencies between 300 and 400 HZ.

The response of conductive bodies such as the ground to these pulses is similar to that of a simple step function, and the analysis of the transient response provides good information on the ground conductivity (σ). In this method the instrument consists of a transmitter that generates half-sine wave-current pulses in a multiturn loop, and a receiver that consists of a pick-up coil connected to a gated coherent detection system. The function of the receiver is to sample the transient secondary field generated by the ground and by conductive bodies lying within the range of the equipment. The receiver output is fed to a recorder which facilitates the measurement of the transient amplitude and rates of decay.

The method is similar to radar in that a primary pulse is transmitted, which is followed by a return secondary signal delayed in time with respect to the primary pulse. But unlike radar, the delay is not caused by the finite propagation velocity of EM waves, as this delay is minute compared with the delay involved in the decay of secondary EM fields induced in the target. Certain advantages exist in the pulse system. For example, when more than one conductor is present, they can be separately identified in the transient response, provided that the conductors are substantially decoupled. Thus if a vertical conductive sheet such as a sulphide mass underlies a horizontal layer of high conductivity caused by surface salinity, two responses would be obtained and could be readily separated. Good conductors which underlie surface zones of conductivity can generally be easily identified by the fact that their transient decay is considerably longer, and samples taken at suitable intervals in the receiver detect these transients whilst excluding surface response.

Measuring the departure from homogeneity of conductivity in both the vertical and lateral sense also has obvious potential in the search for underground water. Many aquifers present a marked resistivity that contrasts with their surroundings, and the study of a three-dimensional conductivity map in conjunction with aerial photographs could prove a valuable tool in the development of water supplies.

GROUND SENSING BY VHF RADAR

It was mentioned that VHF frequencies above 180 MHZ are affected principally by the dielectric constant rather than the conductivity over the full spectrum of conductivity conditions which occur in nature. A further interesting feature of VHF frequencies is that they have skin depths which are substantially greater than for those most radar frequencies, and the penetration is sufficient to be of special value for soil-moisture measurements. Furthermore, the wave lengths of VHF frequencies lie between about 0.5 and 5 meters and are therefore large compared with the surface roughness of most terrain. The reflectivity characteristics at these frequencies are therefore determined more by the dielectric constant than by texture. The relationship between dielectric constant and soil moisture is shown in figure 2. Figure 3 shows the distribution of reflectivity against the dielectric constant above 180 MHZ. From these graphs it can be inferred that reflectivity measurements with suitable instrumentation in the VHF range can provide information on soil moisture content.

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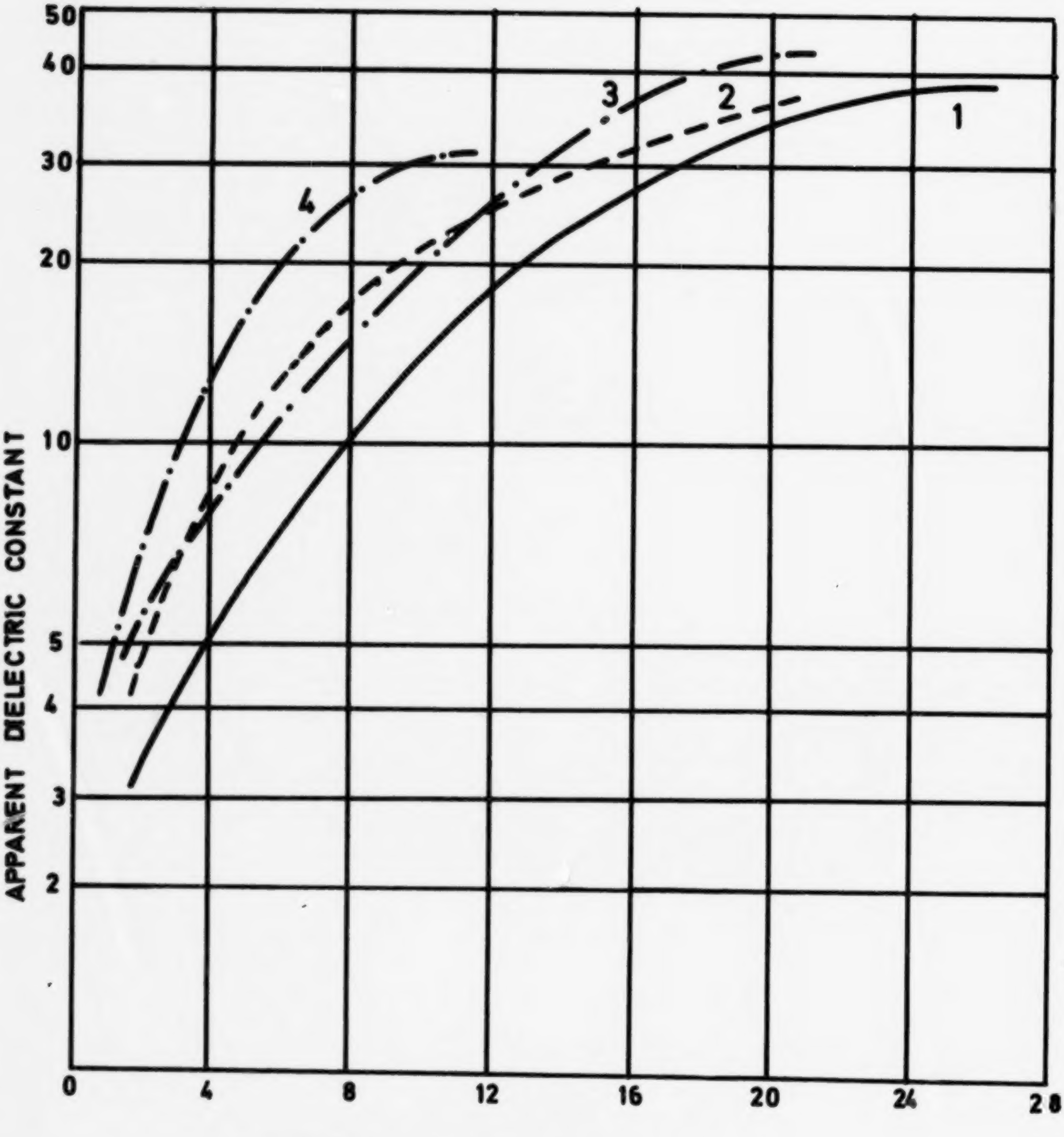

Figure 2. Relationship between dielectric constant and soil moisture (after Smith-Rose).

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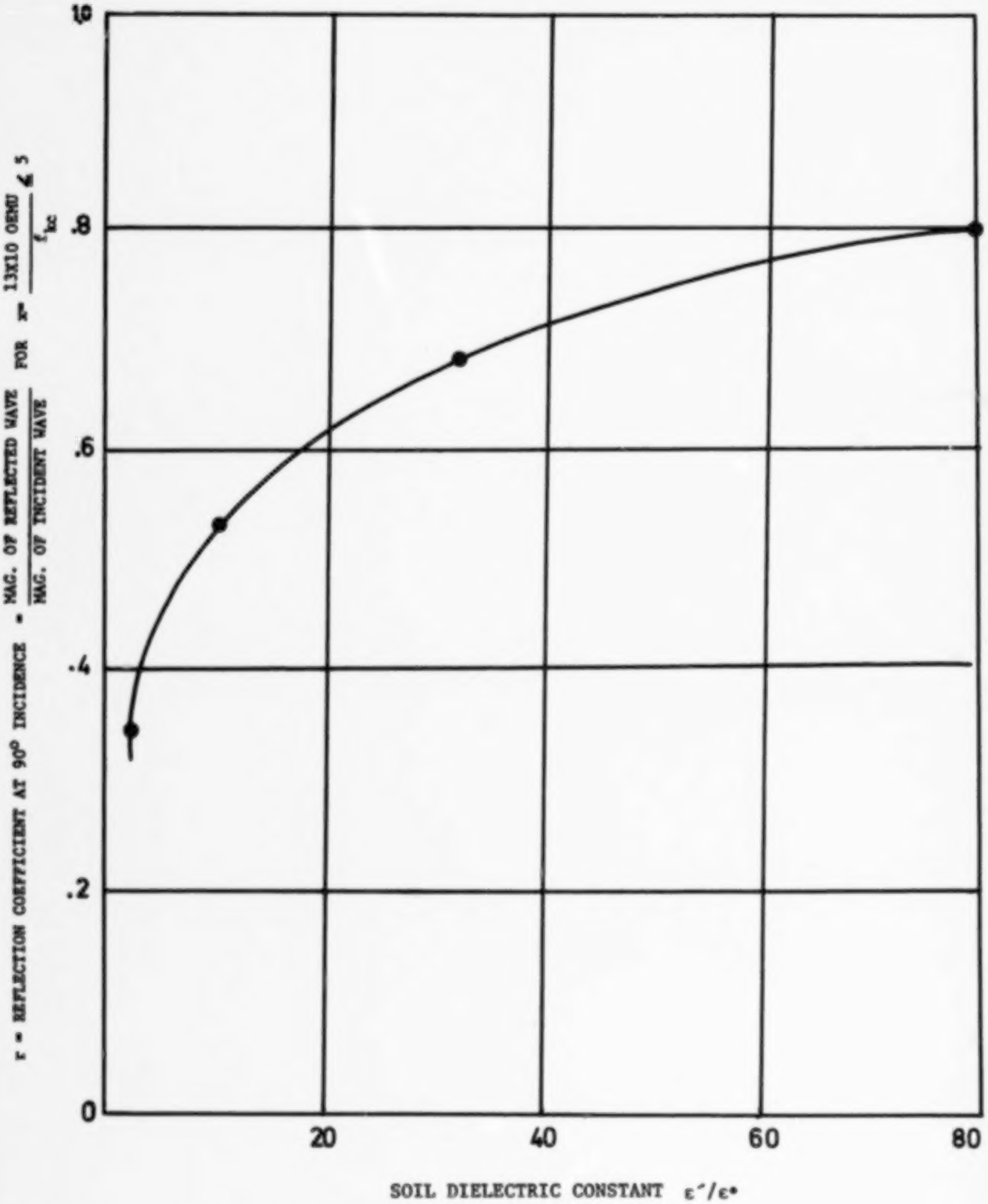

Figure 3. Distribution of reflectivity against dielectric constant above 180 mc.

APPLICATION OF REMOTE SENSING DATA TO FOREST AND RANGELAND INVENTORY

A. Blair Rains, Land Resources Division,
Ministry of Overseas Development, UK

During recent years there has been an awakening of international interest in environmental problems and concern that the renewable resources of land and sea be so managed that sustained production is ensured. Apart from the evidence that world economic problems now occupy the minds of our leaders, there is a naive but widespread belief that modern technology, including that termed, 'remote sensing, will solve environmental and resource management problems.

Planning the management of resources requires accurate up-to-date inventories of the resources 'how much of what where,' and while the emphasis in this paper is on physical resources, the study of human resources in socio-economic terms is often of even greater importance. The study of resources both physical and human is valueless unless it results in an improvement in the wellbeing of individual men and women. There are far too many unused land resource studies, forest and range inventories; their production has been costly in manpower and money and before embarking on new inventories we should attempt to discover why the recommendations of the earlier reports have not been implemented, that is, if this is not known already.

In many countries one government department is responsible for both forests or woodlands and rangelands; woodlands are a source of fuel including charcoal, building materials, grazing, food and fibre; rangelands are used primarily for extensive animal production but may also provide fuel and be used for recreation or tourism. If the ability to regulate and to ensure the satisfactory utilization of forest and rangeland resources is lacking, inventories and management plans are useless. The development of new films, new sensing instruments, satellite platforms and data handling systems must never so engross us that we forget that remote sensing is only a tool in the management of our resources.

The forester was among the first to appreciate the value of aerial photography for forest inventories, and the value of conventional photography both black and white and color for forest surveys is well established.

A forestry inventory is costly in skilled manpower and it should not normally be necessary to repeat a quantified (volume) survey of standing timber, provided that subsequent damage is monitored, felling is controlled, and that regeneration (forest dynamics) is investigated by detailed studies. Uncontrolled extraction or incursions by cultivators, may however necessitate undertaking a new inventory and in such circumstances and in states where forests have never been accurately mapped the use of Landsat data can be a valuable first stage of a multistage approach. The extent of unauthorized extraction or farming incursions in previously surveyed forests may be determined from aerial photography without the necessity of new ground survey.

In Ethiopia King and Blair Rains (1974) have used Landsat imagery (bands 5 and 7) enlarged to 1:250,000 scale to locate by visual examination the main forests within the project area. It was not found possible to discriminate between forest types on this imagery, although it was possible to distinguish montane forest, riparian forest, and Acacia woodland.

After the main areas of woodland have been located, it is necessary to identify forest types and to decide the appropriate method of ground sampling and for this aerial photography at 1:30,000-scale is desirable. The identification of individual species on the aerial photograph is more difficult in forests floristically richer than those of the higher temperate latitudes.

The potential value of the woodland determines the level of sampling on the ground; in a commercially exploitable woodland 2 percent of the total area may be measured; in less valuable stands 1 percent or less will be recorded; a stratified or partly stratified method may be used. These methods are familiar to professional foresters. The groundwork is time consuming, and often exhausting; it requires some technical skill and careful recording, and it is indispensible if inventories are to provide the information on which a sound management programme can be based. Rate of increment can only be satisfactorily determined by measurements on the ground over a period of years. If repetitive satellite imagery is available, it can be used to monitor the extent of more severe forms of destruction such as fire or wind damage, or unauthorized felling if this is extensive.

A number of instruments and systems have been developed for analysing digitised data which may be derived either by scanning aerial photographs or directly from a satellite ground-receiving station; in these instruments the discrimination of forest types can be facilitated by contrast stretching, and if data from two or more spectral banks is available,by ratioing techniques. Hard copy can be obtained from these instruments as a complete print-out or by photographing the monitoring screen.

Like the forester, the ecologist has long recognized the value of remotely sensed data in studying the distribution of vegetation, and rangeland inventories can be considered as special-purpose vegetation surveys which are primarily concerned with the distribution of fodder resources, both herbaceous and woody.

In most rangeland inventories the investigators are concerned with large, sparsely vegetated areas (a survey of grazing resources in the Botswana Kalahari involved 214 000 km^2). The synoptic view provided by Landsat imagery is particularly valuable as a means of identifying the main ecological boundaries; its low resolution is a positive advantage as the operator is not distracted by the detail present in aerial photographs nor by the lines between individual photographs which appear in aerial photo-mosaics. Even with small-scale aerial photography, handling the very large number of photographs can be tiring; aerial photography is needed, however, in order to determine the character of each vegetation community.

If air survey resources permit, infrared color photography at 1:20,000 scale of selected areas or transects, flown late in the growing season, would be most valuable (commercial air survey companies are reluctant to undertake projects of this type). The fieldwork is planned to validate vegetation boundaries and to determine the botanical composition of each community; quantified records of cover are desirable.

Most CENTO countries already possess satisfactory rangeland inventories, even though misuse may be causing both rapid deterioration in cover and changes in composition.

The ability to monitor trends and also to reliably estimate the seasonal production of fodder on a countrywide basis might justify effort and investment. It would involve monitoring sample plots which would be cut, clipped, or plucked over a number of years and to correlate the yields of herbage and browse with reflectance values measured at the time of cutting. Such an investigation could involve sophisticated sensors and data-analysing equipment or might be undertaken most simply by multiband photography.

Before any such investigation is undertaken or any attempt is made to introduce an operational system, it is essential to determine locally the possible usefulness to the livestock industry of timely information about fodder resources. It is essential to ask, 'how do our nomadic or seminomadic pastoralists obtain information about distant rangelands at the present time,' and 'could their movements be more efficiently organized?'

We realize that remote sensing is not a toy but is a valuable tool in the assessment of forest and rangeland resources. Resource inventories are necessary for planning the management of renewable resources, but they are costly to undertake. In many countries it is more important to attempt to implement existing plans for development than to undertake new surveys. This is a more difficult task, for not only must there be government commitment to the program and the involvement of dedicated field staff, but there must also be understanding and cooperation by individual men and women whose lives will be most affected.

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AERIAL PHOTOGRAPHY AND SATELLITE DATA IN LAND USE STUDIES

By A. Blair Rains
Land Resources Division
Ministry of Overseas Development, UK

INTRODUCTION

The most useful part of many expensive integrated land resource surveys undertaken by the Land Resources Division for overseas governments has been the quantified land use data. This data indicates how much land is currently cultivated, and the reserve of cultivable land, and is often provided within administrative units.

Before undertaking any investigation of this kind, it is necessary to decide how many categories of land use are required, the degree of accuracy and the form in which the information will be most useful; the source of data, its resolution, the instruments, and the time available for its examination may in turn affect the number of categories which can be identified and the presentation of results.

For many purposes it may only be necessary to identify a small number of categories, for example the following:

Land in cultivation cycle (arable and temporary fallow)
Old fallow (field boundaries still discernable)
Noncultivated but cultivable (reserve farm land)
Uncultivable
Settlements, roads

For other purposes it may be better to determine the intensity of cultivation within each of a series of units of land which are subsequently mapped. In some investigations it may be possible to combine land use data with either a soil map or a land-capability map.

In some circumstances a country or a region may require a more comprehensive description of resources involving the discrimination of a larger number of terrain categories such as:

Natural woodland
Shrubland
Grassland
Firewood plantations
Tree crops
Arable land
Fallow
Sown pastures

The resolution of the imagery may limit the number of categories that can be identified, and the discrimination of a large number of features will be relatively more time consuming. In many developing countries not only are fields small, but a common practice is to interplant two or more crops; the combined result is to prevent the identification of crops by any practical method of remote sensing.

The results of land use studies may be presented in map form and/or as quantified information. In many surveys the presentation of results has involved elaborate map production; conventional mapping is costly and the map may rapidly become out-of-date; the use of a transparent overlay to a suitable map may be cheaper and quicker. For some purposes a geometrically uncorrected photocopy or a print-out may be as satisfactory as a conventional map.

The value of the map or print-out is enhanced if the area of the mapped units is stated. In some projects it may only be necessary to determine the area of each category; this quantified information is usually related to another environmental unit, i.e., a land system or soil unit, or it can be related to an administrative unit, i.e., a district. In many long-term investigation, including socio-economic studies, it may be necessary to monitor changes in the land-use pattern, and the method of monitoring should be planned before the start of the investigation.

Some methods of using remotely sensed data for land use study are considered below.

VISUAL METHODS

Conventional aerial photographs under the stereoscope or Landsat imagery can be annotated, the information transferred to a suitable base map, and areas measured. This method requires no elaborate equipment, and experienced workers can produce good results.

A visual method developed in the Land Resources Division (Alford and others, 1974) involves the identification of the terrain feature at a large number of sample points on stereoscopically viewed aerial photographs. The identifications have been recorded directly on standard 80-column punch cards which are subsequently computer analysed. If the photographs have previously been annotated with administrative boundaries and soil or land capability boundaries, this information can also be included on the card and in the analysis. We recently extended the method to an assessment of land-use patterns using aerial photomosaics, and we believe that it would be applicable to enlargements of Landsat imagery. Although the location of each sampling point can be calculated, results have only been presented in tabular form. The method has provided reliable results which we believe have been useful. It requires computer time.

PHOTOGRAPHIC METHODS

Afga isodensity (contour) film has been used to obtain from black and white photographs a series of slices recording all areas of the same optical density (tonal value). Several slices have been used as masks to produce a colored thematic representation of the original photograph. The method requires modest photographic facilities. Different terrain features with similar optical density are recorded as one category and this can be misleading. The variation in the tonal value across a single photograph of along a line of photographs can present problems.

Color enhancement of multiband photography in color-additive viewers allows the operator to vary the color, brightness, and in some instruments the saturation of each image in order to discriminate features of interest more easily. A number of instruments are available; in some instruments registration of the images may be difficult or the controls inaccessible. Most instruments are limited to 70-mm film and hard copy has to be obtained by photographing or tracing the image on the screen. It is not possible to rapidly examine a large number of images.

INSTRUMENTS

Early instruments for image analysis were analogue devices and had a limited capability. Newer instruments are digital and very versatile. In most instruments the image is scanned by a television camera or other scanning device, digitised, processed, and displayed on a screen. Instruments are usually designed to interface with a computer, and with appropriate programs a variety of tasks can be performed. Some instruments accept digital data such as that from Landsat. Hard copy can be a color film print or a computer print-out.

A single image can be density sliced and the features of each slice measured, or the image can be displayed (enhanced) in color. Terrain features can be accurately identified by the analysis of multiband data and supervised programs have given reliable results. Instrument analysis is useful for the detection and measurement of spatial or temporal changes.

With the development of computer programs, textural differences can be distinguished, and this will further improve the reliability of feature identification.

Instrument analysis seems most appropriate for the examination of a relatively small number of images, and as yet there are no reports of its application to an operational project involving a large number of aerial photographs. A number of instruments for image analysis are available but their cost will represent a major item of expenditure in many government departments. It is necessary that the cost-benefit of instrument image analysis be assessed and that the human aspects are not neglected in this assessment before any investment is recommended. In order to gain an appreciation of the capabilities and the limitations of image analysis, it is desirable that those involved in the interpretation of land-use patterns and other features should gain first-hand experience on an instrument over a period of several weeks.

CONCLUSION

Various methods of land-use analysis using remote sensing data have been discussed; regardless of the method employed, field work is an essential part of most projects. Results must be presented in an easily usable form and the need for timeliness may preclude elaborate forms of presentation. The possibility that additional information might subsequently be needed must be anticipated when planning the project; similarly, provision must be made to monitor change and to relate the results of earlier and later studies, even though the methods of analysis may be different.

Whatever technique we may use, it is necessary to remind ourselves that land-use analysis is a source of the information needed for planning development and in the allocation of resources for the benefit of individual men and women; it must never become an end in itself.

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THE MAPPING OF SOIL ASSOCIATIONS BY REMOTE SENSING TECHNIQUES

By Dr. L. F. Curtis
University of Bristol, U. K.

Soil is of major importance as an economic resource because it supports plants and animals that provide man with food, shelter, and clothing. It is also important as the foundation material for the buildings erected by man. Different concepts of soil have, therefore, been developed by agriculturalists and engineers.

The agriculturalist finds the whole of the soil profile significant to plant growth: the surface (A) horizon because it is the seat of biological activity and the principal source of nutrients; the subsoil (B) horizon because it affects drainage, soil moisture retention, aeration, and root development. The underlying parent material (C) horizon is mainly significant because it may contain weatherable minerals yielding nutrients, and its texture may affect permeability.

In contrast, the engineer normally defines soil as "the unconsolidated sediments and deposits of solid particles derived from the disintegration of rock." For the engineer the term soil includes all regolith material and a sharp demarcation between rock and soil is no longer made. The engineer is normally more concerned with what the agriculturalist would term the C horizon.

MAPPING OF SOILS

It was not until the 1920's that soil units were mapped on the basis of the soil profile and A, B, C horizon designations. It was soon recognized that soils are very variable in their properties and it has become usual to allow up to 15 percent of soil within a mapping unit to vary from the described attributes of the unit. Soil categories used by agriculturalists include Great Soil Groups, Soil Series, Soil Associations, and Soil Phases. Attention is focussed here on the Soil Association. The soil association is a group of defined and named units of soil classification (taxonomic units) regularly associated in a defined proportional manner. The levels of grouping and definition vary according to the needs of the map. Thus the soil association can consist of a broad grouping of Soil Groups (e.g., Psammustents and Camborthids) or narrower groupings of soil series units. The present resolution of Landsat data is best suited to the former. Concepts of soil associations vary considerably, and the groupings of Soil Groups may be based on parent material, vegetation, hydrologic, or landform characteristics (Western, 1972).

Aerial-survey techniques led to the development of interpretation methods such as pedological analysis (Buringh, 1954) and land system analysis (Christian, 1958). The development of color and infrared color photography provided more sensitive data for the interpretation of soil conditions. In particular, infrared color has been found to be valuable for the mapping of vegetation and soil conditions. The advent of multispectral sensing systems has led to efforts to distinguish the multispectral signatures of soils. The derivation of unique spectral signatures for soil conditions is complicated by environmental variables such as soil moisture state, cultivation, per cent crop cover, and vegetation type and stage.

In arid and semiarid regions, soil mapping and classification are often concerned with sedimentary sequences which may be well seen in aerial and satellite data. Thus terrain mapping from satellite data can provide useful synoptic information concerning the soil associations present in a region. The soil scientist and agriculturalist are interested in the dynamics of these soil systems. Landsat affords the prospect of examining an area at intervals of time to assess changes in soil state, such as build-up of salinity, waterlogging, crop cover or erosion. Although computer or machine processing may be useful, commonly rapid appraisal of the imagery by visual interpretation is desirable.

As an example of visual interpretation, Landsat data in the form of a false-color composite image at a scale of 1:250,000 has been used to produce terrain unit maps showing soil associations of parts of northwest India. The interpretation was made by R. C. Bhandari (Haryana University, U. N. Soil and Water Management Project) working with the writer.

Nine types were identified as shown on the map (fig. 1), on which all except Terrain type 5 could be expected to be permanent, though changing, parts of the soil landscape. In the case of type 5, ephemeral flood basins occurring in Psammustents were outlined, but these features may not persist from year to year.

Further images of the same region will be examined in order to monitor the nature and rate of change in surface conditions in this important agricultural region. The principal objective will be to assess the extent of surface waterlogging and the incidence of salinisation. Such a comparative study carried out over several years should provide valuable information for those engaged in reclamation schemes.

In the following pages the location, methods, and terrain types are described in turn.

BEST DOCUMENT AVAILABLE

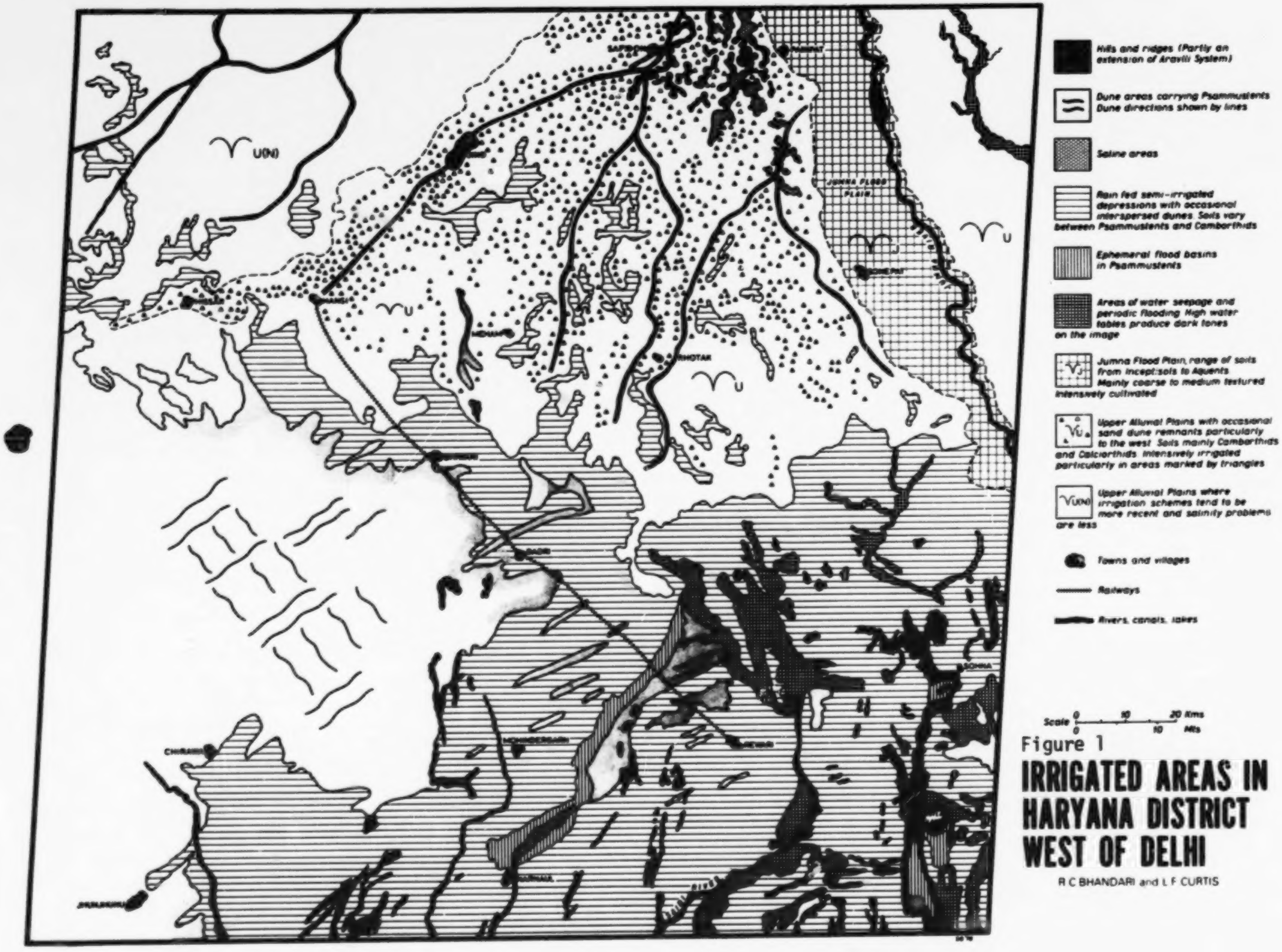
Hills and ridges (Partly an extension of Aravili System)
Dune areas carrying Psammustents Dune directions shown by lines
Saline areas
Rain fed semi-irrigated depressions with occasional interspersed dunes. Soils vary between Psammustents and Camborthids
Ephemeral flood basins in Psammustents
Areas of water seepage and periodic flooding. High water tables produce dark tones on the image
Jumna Flood Plain, range of soils from inceptisols to Aquents. Mainly coarse to medium textured intensively cultivated
Upper Alluvial Plains with occasional sand dune remnants particularly to the west. Soils mainly Camborthids and Calciorthids. Intensively irrigated particularly in areas marked by triangles
Upper Alluvial Plains where irrigation schemes tend to be more recent and salinity problems are less
Towns and villages
Railways
Rivers, canals, lakes
Scale 0 10 20 Kms
0 10 Mls
U(N)
U
U
U
JUMNA FLOOD PLAIN
ROHTAK
SOHNA

Figure 1

IRRIGATED AREAS IN HARYANA DISTRICT WEST OF DELHI

R C BHANDARI and L F CURTIS

LOCATIONS

Haryana State in India extends over an area bounded by latitudes 29°39' to 30°55'N, and longitudes 74°27.8'E to 77°36.5'E. Landsat-1 imagery is available for this area for observations made on the following dates: November 15 and November 16, 1972.

A false-color composite on a scale of 1:250,000, covering areas approximately within latitudes 27°30' to 29°30'N, and longitudes 75°45' to 77°00'E was obtained for visual interpretation. The objective of the interpretation was to place boundaries around different soil, land use, and hydrological conditions. In particular, attention was given to delineation of areas of salinity and waterlogging occurring within different physiographic and land use types.

The imagery covers most of the areas within the districts of Gurgam, Hissar, Mahindergarh, Bhiwam, Jind Rohtak, Sonepat, and parts of Karnal within the State of Haryana, which is comprised of 11 districts. In addition, the imagery covers considerable areas of northwestern districts of Rajasthan State. The study area is in the northwest part of India at a distance of about 1600 km from the sea. Thus it lies at the periphery of the southeasterly Monsoon region. The Monsoon season extends from the months of July to September. From October to the end of June, the weather is generally dry, apart from occasional light showers caused by westerly winds. Annual rainfall ranges from about 300 mm in the south of the area to 900 mm in the northeast. The area as a whole can be said to have a semi-dry monsoon climate in which the summers are very hot, but winters are fairly cool. Temperatures in the months of May and June may range from 44°-48°C, whereas in January the temperature may fall to the freezing point. The relative humidity remains low throughout most of the year but is lowest in the summer months of April, May, and June. Evaporation losses exceed precipitation amounts throughout the year, apart from the monsoon months of July and August.

METHODS AND MATERIAL

The first Earth Resources Technology Satellite--Landsat 1--was launched into a near-polar orbit at an altitude of 915 km on July 23, 1972. It operates in a circular, sun-synchronous path, encircling the Earth every 103 minutes, completing 14 orbits per day, and viewing the entire Earth every 18 days. The principal sensor from which data has been received is the Multispectral Scanner (MSS) which is a line-scanning device that uses an oscillating mirror to scan at right angles to the spacecraft direction. Optical energy is sensed simultaneously by an array of detectors in four spectral bands from 0.5-1.1 μm. From this data, four synchronous images can be obtained, each in a different waveband as given below:-

a) Band 4 (green)	0.5 - 0.6 micrometer
b) Band 5 (lower red)	0.6 - 0.7 micrometer
c) Band 6 (upper red - lower infrared)	0.7 - 0.8 micrometer
d) Band 7 (near infrared)	0.8 - 1.1 micrometer

After receiving the data from Landsat-1, the various National Aeronautical Space Administration (NASA) data-receiving stations transmit the data to Goddard Space Flight Center, Maryland, U.S.A., for preprocessing. Subsequently, the EROS Data Center, Sioux Falls, South Dakota, U.S.A., receives the data and produces formats for sale to users. The formats available include photographic film positives and negatives, photographic prints, and computer-compatible tapes (CCT). For the purpose of this study, a false-color composite print derived from bands 4, 5, 6, and 7 (scale 1:250,000) was used. This was studied visually with the aid of a monoscopic magnifier. As a result of the interpretation of the satellite image, a map was prepared that delineates eight terrain units. The principal characteristics of these units are shown as follows:

Terrain type I -
Geological outcrops forming hill and ridge landforms

In the satellite image, rock outcrops appear as brick red-reddish brown colors and have sharp boundaries against adjoining sedimentary deposits. These rocks represent exposed parts of the Aravalli System which is comprised of Precambrian quartzite schist, quartzitic sandstone, subschistose quartzite, mica phyllite, and crystalline limestone. The crystalline limestones belong to the Archean system, whereas the other rock types represent the Cuddapah system. In places these Precambrian rocks are veined with pegmatites and quartz. Most of the exposures of the Aravalli System detected in the image lie in the districts of Gurgam, Mahindergarh, Bhiwani, and Hissar.

Terrain type II -
Dune field systems carrying Psammustent soils

The characteristic landforms of linear dune fields can be seen to dominate in the southwest of the region. The dominant dune direction is SW-NE, which conforms to the dominant wind directions associated with the monsoon. However, a secondary pattern, formation of which is uncertain, can be detected trending at right angles to the dominant dunes. Most of the dune fields imaged in pale brown or yellowish-brown colors.

The Psammustent soils associated with the stabilized dunes are coarse-textured sands or loamy sands commonly extending to depths greater than 50 cm. The water in these soils is held at low water tensions of less than 15 bars. However, within this terrain unit, one may distinguish between the dune systems of the southwest and the redeposited dune material in the northern districts. In the northern districts of Hissar, Bhiwani, and Mahindergarh, the aeolian material has been reworked in alluvial forms and flood plains. Thus, some levelling of the land surface has taken place together with resorting of particle size which has resulted from the action of the Ghaggar, Sarswati, Chantang, Saibi, Kansoti, and Manasue Rivers.

Terrain type III - Saline areas

Saline areas produce bluish-white tones on the imagery. Most of these areas occur as scattered patches contrasting strongly with dark gray tones of waterlogged or irrigated areas. Some occur in close juxtaposition with red and purplish-red tones of cropped areas. The soils in which the saline patches occur are mainly Orthids, the dominant soils being calcareous and noncalcareous Natric Camborthids and Natric Calciorthids. The salts have accumulated because of poor soil drainage and subsurface water accumulation due to canal floodings and periods of heavy rainfall (see also Terrain type VI). The subsurface moisture is brought to the surface by capillary action under conditions of high evapotranspiration. Additional imagery is being examined in order to determine whether variations in surface salinity can be identified by use of Landsat data.

Terrain type IV - Rainfed semi-irrigated depressions with occasional dunes

This terrain occurs mostly in the southern districts of Gurgam, Mahindergarh, Rohtak, and also in Hissar. It adjoins Terrain type II in places. The dominant soils are water-stabilized Psammustents on sloping ground; Camborthids and Calciorthids occur in the intervening depressions. These soils are watered either by nonperennial rivers and canals, or by occasional flooding following rains. Such areas can be distinguished from the dry dune systems (Terrain type II) by light green tones and by red or purplish-red mottlings that indicate vegetation or crop cover.

Terrain type V - Ephemeral flood basins in Psammustents

These represent moist areas at the time of imagery. They are not necessarily permanent features.

Terrain type VI - Areas of seepage water and periodic flooding

Soils having high water tables and wet surfaces are imaged in dark tones on the Landsat imagery. Several such areas can be identified in the area of study, mainly in the districts of Sonepat, Karnal, Jind, and the northern parts of Rohtak and Hissar. These regions lie mainly north of the Delhi-Sirsa road. The waterlogging is due to flooding from the Rivers Ghaggan and Sarswali and water seepage from the Western Jumna and Sirhind Canal Systems, which are more than 60 years old. It is in this terrain type that the twin problems of saline/alkali soils and high water tables are becoming increasingly acute. Each year more land is falling out of cultivation because of these problems.

Interspersed throughout Terrain type VI are patches of Terrain type II (saline areas). Indeed, the saline areas are largely the culmination of long periods of high water tables and high rates of surface evaporation. An important aspect of extensions of this study will, therfore, be to measure variations in extent of both waterlogging and surface salinity.

Terrain type VII - The Jumna flood plain

The River Jumna forms a major physiographic element in the area of study. The recent alluvial deposits are coarse to medium textured and are bounded on both sides of the river valley by river bluffs. The soils consist of freely draining Quarzipsamments and Psammaquents which are intensively cultivated and produce a variety of agricultural crops.

Although the water table is sometimes high, there is no prolonged waterlogging, owing to lowering of the water table when water is pumped for irrigation.

Terrain type VIII - Upper alluvial plains with occasional sand dunes

Much of this land consists of good agricultural land. As a result, the Landsat image records these areas in red (cropped areas) and blue (fallow areas) tones. The parent materials of the majority of the soils consist of ancient alluvial deposits, probably of Pleistocene age. The range of textures and soils is considerable, but they are mostly Entisols and Aridisols with calcareous and noncalcareous subsoil phases. The water table is fairly low and some patches of aeolian sand have not been fully stabilized. These are indicated by light yellow tones in the imagery.

Terrain type IX - Upper alluvial plains where irrigation schemes have been recently introduced

This terrain unit is essentially similar to that of VIII described above, except that irrigation schemes have been introduced recently. The image tones are predominantly blue (fallow fields) with some red (emergent crops and tree areas). Major feeder canals can be identified on the imagery.

The soils are similar to those of Terrain type VIII and the water table is more than 10 meters deep. As a result, salinity and alkalinity hazards have not developed extensively at the present time.

CONCLUSIONS

Landsat imagery of parts of northwest India can be used for regional land use and soil association mapping. The principal advantage of the Landsat programme is that it provides for automatic coverage at 18-day (9-day since the launch of Landsat 2) intervals. This offers the opportunity of repeatedly monitoring the surface conditions in this important agricultural area. Thus the extent of salinisation and waterlogging can be compared seasonally and from year to year. Sample areas within the study area should be examined in greater detail using precision-processed imagery. Such studies might ultimately yield training set data when correlated with ground observations. These may then be used to provide algorithms for automatic monitoring techniques.

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GROUND MONITORING FOR AIRBORNE AND SPACE STUDIES OF LAND USE AND SOIL CONDITIONS[1]

By L. F. Curtis
Department of Geography, University of Bristol, U. K.

DEVELOPMENT OF REMOTE SENSING TECHNIQUES FOR CROP AND SOIL STUDIES

Many scientists who made war-time observations from the air in 1914-1918 were interested in the peacetime applications of this method of viewing the surface features of the earth. Bushnell (1929) pointed to the uses of aerial photographs as base maps in field operations. Aerial photographs were used in land studies in various parts of the world during the inter-war years. Prescott and Taylor (1930) reported close relationships between vegetation associations seen on air photographs and soil types in irrigated areas of Australia. Robbins (1934) mapped some 3,000 square miles of Rhodesia by means of interpretation of vegetation cover and produced a generalized soil map. However, the outstanding contribution of this period was that made by Bourne (1931) in his classic monograph on air surveys in relation to soil survey. This included a penetrating analysis of the problems of identifying landscape categories which were meaningful in soil and vegetation studies.

During the 1939-1945 war, there were advances in photographic techniques and interpretation methods. Following the war, aerial survey was increasingly employed in forestry, land use, and soil surveys. Photo-interpretation techniques were developed by Jenkins et al (1946); Hills (1950); Wieslander and Storie (1953); Sisam (1947); Spurr (1960); Buringh (1954a, b) and Veenenbos (1957). At about this time, many photographic keys were developed for soil and land use studies (Sager, 1951; O'Neill, 1953; Landis, 1955, and Roscoe, 1955). There were also some attempts to measure the accuracy of photo-interpretation of soil boundaries by comparing interpreted boundaries with soil boundaries mapped on the ground (Pomerening and Cline, 1953; Curtis, 1963).

It is interesting to note that, at this period, the possibilities of identifying soils using various films (panchromatic, color 2-3 layered) were discussed (Liverovskii, 1957). In addition, there were studies of the reflectance characteristics of different soil types, particularly in the infrared part of the spectrum (Gaveman and Liverovskii, 1953; Andronikov, 1958). Thus, the present day interest in the spectro-photometric characteristics of vegetation and soils was foreshadowed by earlier work.

Many of the studies in the 1960s were based on the terrain evaluation approach (Beckett and Webster, 1965; Brink et al, 1966). This approach resembled the "land system" technique employed by the Land Research and Regional Survey Organization, C.S.I.R.O. in Australia. Indeed the concepts of land units and land systems were propounded by Christian (1958). This period also saw the breakthrough by film manufacturers in 1960, which succeeded in producing a range of color emulsions with speed and resolution characteristics comparable to panchromatic films. This development ushered in a series of studies which indicated that color (including reversal color) yielded more accurate data on land use, crop identification and soil conditions than panchromatic photography (Mintzer, 1968; Anson, 1970; Simakova, 1964). Attempts were made to compare field soil colors measured by the Munsell system with Munsell values of the soils as recorded on color photographs (table 1) (Parry et al, 1969). Also laboratory measurements of the Munsell color of dried soils were made and the soils were photographed with color and infrared color films (Gerbermann et al, 1971). Optical density measurements made on the color film transparencies with a Joyce Loebl Microdensitometer using filters showed that the soils could be separated into groups on the basis of significant differences in densities. Thus, the last decade has seen the development of multispectral photography and color enhancement techniques for studies of soil and land use conditions (Curtis, 1973, 1974; Carroll, 1973).

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The development of multispectral (multiband) photographic techniques has been accompanied by technological development of non-photographic (scanner dependent) systems operating over a wide range of the electro-magnetic spectrum (figure 1). Thus, vidicon cameras, infrared scanners and radiometers, microwave scanners and radiometers, microwave radars and lidars have now extended the range of wavelengths which may be used in remote sensing studies. This technological advance has led to the rapid extension of multispectral techniques and the search for spectral signatures of soils, crops and land surfaces. For the most part, spectral signatures such as those obtained by Condit, 1970, (figure 2) and by the University of Michigan for the Air Force Target Signatures Measurement Program (Leeman et al, 1971) have been made under laboratory conditions. It is evident, however, that there will be an increasing demand for field data as well as laboratory data for the calibration of sensors and checking of data processing techniques.

The term "ground truth" is often used in a somewhat loose sense to include any information concerning a target area, including published maps and census data. In this discussion, ground truth refers to data obtained for the identification and description of a target area by means of field sampling (sometimes followed by laboratory analysis), verbal/written descriptions and instrumental measurements from ground based platforms. Some of the current problems and practices in ground truth data collection for accurate description of a training area for use in remote sensing studies are discussed below.

BEST DOCUMENT AVAILABLE

		Munsell notation for soil colour in field		Munsell notation for colour photos	
Soil group	Soil series and type	Dry	Moist	Predominant colour/range	Other colours
Podzol	Ivry fine loamy sand	10 YR. 6/3	10 YR. 5/3	10 YR. 6/1 – 10 YR. 4/1 – 2	10 YR. 8/0 – 4 10 YR. 7/0 – 4 10 YR. 3/1
Brown podzolic	Lesage sandy loam	10 YR. 7/3 5 Y. 7/3	10 YR. 4/3 5 Y. 7/3	10 YR. 8/0 – 4 10 YR. 4/0 – 4 5 B. 8/1 5 B. 7/2 5 BG. 6/1 5 BG. 7/1	5 B. 4/1 7·5 YR. 6/2 7·5 YR. 5/2 – 4
Grey gleisol	Brandon clay	5 Y. 7/2 10 YR. 4/1	2·5Y 4/2 10 YR. 3/1	5 B. 7/0 5 B. 4/0 – 1 5 BG. 7/0 – 1 5 BG. 6/0 – 1	7·5 YR. 6/4 7·5 YR. 5/4 10 YR. 8/0 – 1 10 YR. 6/0 – 1

Table 1. Soils of the Lac Bevin Basin and their characteristics. (After Parry *et al.* 1969.)

Note: Overlap occurs between photo colours of Ivry and Lesage (e.g. 10 YR. 4/1) and between Lesage and Brandon (e.g. 5 BG. 7/1). Good correlation exists between field and photo colours of Ivry series but poor correlation occurs in Brandon and Lesage.

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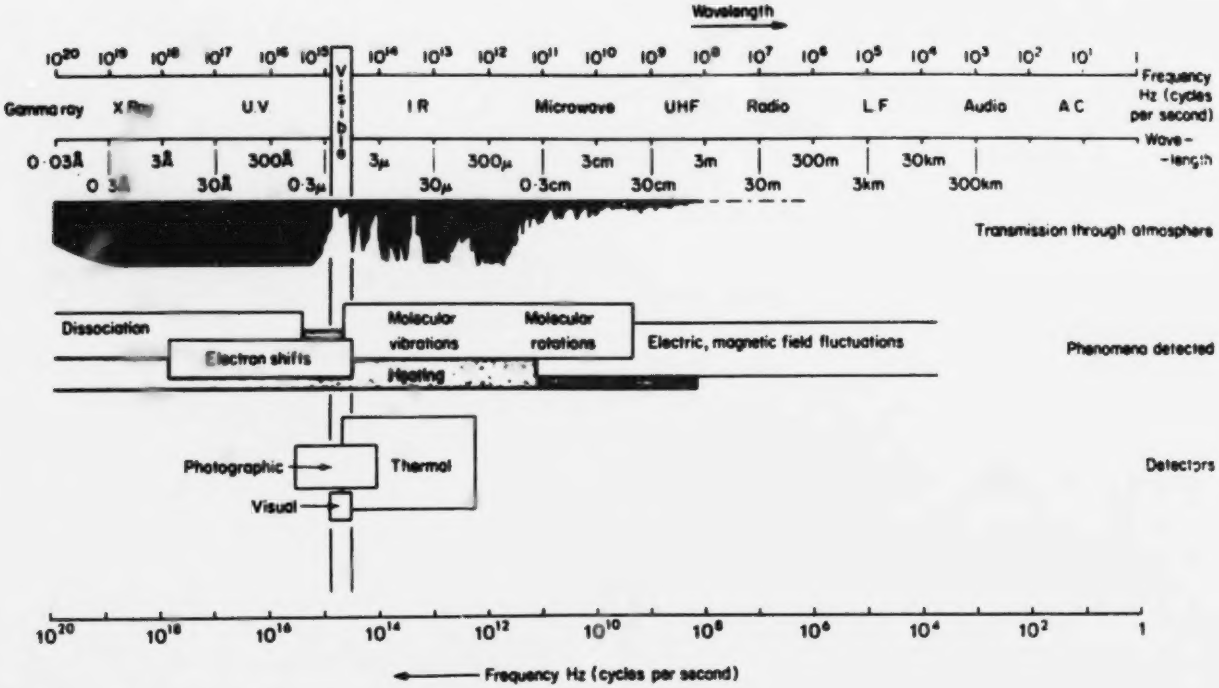

Fig. 1. Electromagnetic spectrum and sensing devices.

BEST DOCUMENT AVAILABLE

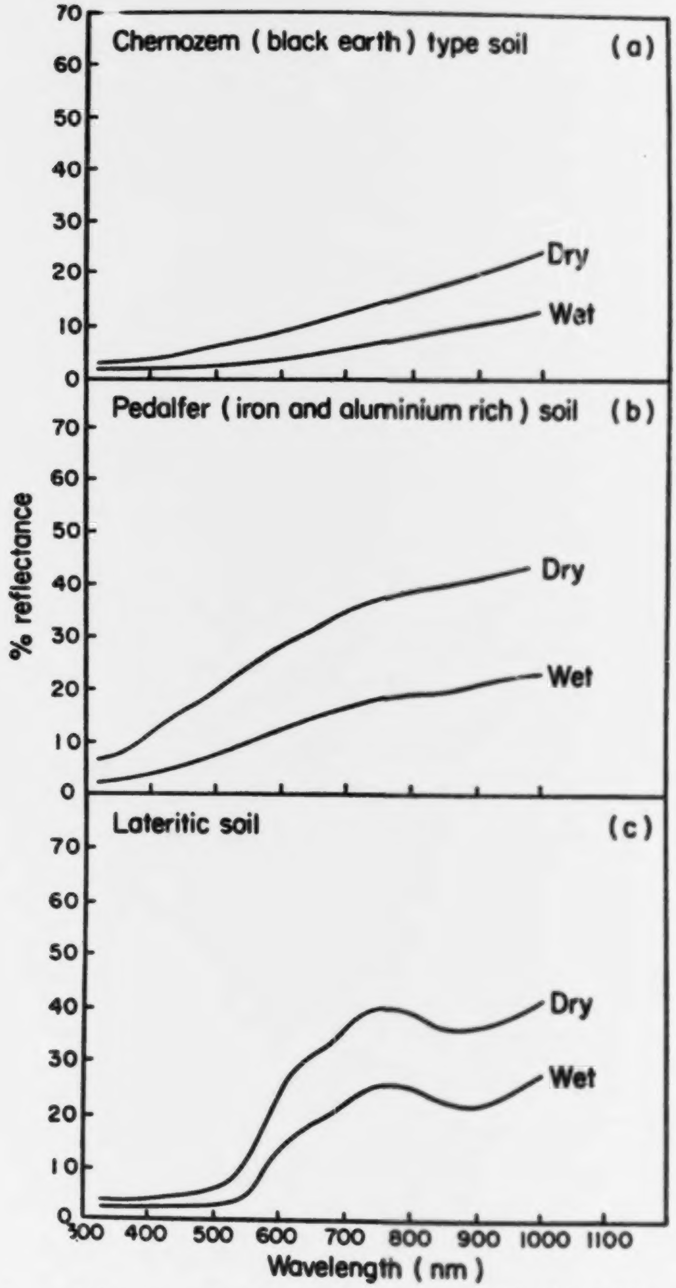

Fig. 2 Spectral signatures of selected soils when imaged in the visible range of the spectrum. (After Condit 1970.)

GROUND TRUTH FOR LAND USE/CROP STUDIES

Range of data

The range of crop data to be collected depends on the objectives to be served by the data. Where the objective is to check the accuracy of identification of land use the data can be limited. However, where data is required for explanation of sensor response or calibration of sensor performance, the range of data appropriate is likely to be considerable. Purdue University Laboratory for Agricultural Remote Sensing (LARS) initially adopted a scheme in which crop species, row width and direction, height of crop, percentage crop cover, general crop condition and special field conditions were recorded. Subsequently, planting technique (e.g. broadcast or row planting), date of planting, date of harvest and variety of species were also recorded (LARS, 1968). For British conditions investigators have adopted a recording system which includes land use, crop stage, crop height, range and pattern, crop color and pattern, disease type and extent, weed species and density, husbandry (ploughed, harrowed, drilled, rolled, wheelings), grazing method, livestock, per cent soil exposed (Curtis and Hooper, 1974).

The LARS system includes interviews with farmers as well as field observations. Thus information such as planting time was collected several months after the area had been overflown. After the farmer interviews were completed, the ground truth data were key-punched on computer cards, processed and stored on magnetic tape. A computer programme then provides a print out on any particular fields or field of interest, or for specific information for a particular group of fields (table 2).

Problems of data recording

The principal problems in data recording in both American and British studies have been in respect of estimates of per cent crop cover, crop color description, crop pattern descriptions and crop height measurement. Estimations of percentage crop cover are difficult to make, particularly in a tall crop. In some row crops such as soyabeans it is possible to measure row width and width between rows and thereby calculate the amount of cover. Quadrat studies are time consuming and one observer may only cover approximately 25 fields per day. In the case of cereal crops it has been possible to establish relationships between crop stages as recorded by a standard system (M.A.F.F. 1971) and percentage leaf cover (see Curtis and Hooper, 1974). In many crops, however, the only solution seems to be that of photographic record, although hand held photographs often contain inaccuracies due to perspective, shadows and image distortion. Crop color description can be achieved by matching colors with Munsell color charts. However, color matching has been found to be difficult due to factors such as shadow within the crop, soil exposure, crop texture, aspect of the field, leaf com-

BEST DOCUMENT AVAILABLE

Serial number of observation . . . 366
Field designation A–1–12

Size of field	35 acres	Soil types	Elston L, Elston SIL
Primary species	Oats	Variety	Clintland
Planting technique	Drilled		
Row direction	Circular	Row width	20cm
Yield	100 Bushels		

Pertinent dates	Date	Crop	Density factors Height (cm)	Density factors Cover (pct)	Treatments Date	Treatments Treatment
Planting . . . March 15	May 6	Oats	005	00		
	June 28	Oats	080	80		
	July 25	Stubble	025	85		
	Sept 13	Stubble	030	99		

Other pertinent information. Field was combined in two separate parts. Slides 34, 48.

Table 2 An example of the format of a computer printout. (After LARS 1968.)

position, lighting conditions, viewing angle and orientation of leaves. It is considered that recording of Munsell Hue and Value figures only are justified. Even these parameters are difficult to evaluate in a rigorous manner. In view of this problem, it seems clear that photometric methods must be developed. Brach and Wiggins, 1967; Drewett (1974). The Plessey Reflectance Spectro-Radiometer has been designed as a research tool for the remote measurement of surface reflectance spectra (plate 1). A simple portable spectrophotometer of the type shown in (plate 2) can measure light reflectance in the range 0.4 microns - 1.1 microns. Crop pattern description from ground level observations can be very subjective with considerable variation between observers. The principal problem is concerned with transient patterns (e.g. plant disease patterns) and these are probably best recorded photographically, although the oblique view in ground photography often leads to loss of information. Cherry picker platforms or light aircraft surveys are desirable, and the use of these is discussed below. Crop height measurement presents some difficulties in that it is sometimes difficult to decide which part of the plant should represent the active (reflecting) surface. Thus, in the U.S.A. where maize was being observed in July, it was not clear whether heights should be measured to the top of the tassel or to the top leaf (LARS, 1967).

Platforms for ground data recording

As a result of the difficulties encountered in making observations at ground level, cherry picker platforms have been used for photographic and sensor recording. In the LARS studies, a field van containing all the necessary measuring equipment and its own power source has been used. The van roof can be used for observation, or the cherry picker bucket can be used up to a height of 15 meters. A schematic diagram of the LARS instrumentation is shown in figure 3.

The cherry-picker type of vehicle is not well suited to cross-country traversing. Problems, therefore, occur where ditches on either side of the road keep the cherry-picker bucket at some distance from the field, so that only end rows can be recorded at vertical angles. As a result of these difficulties, more complete and representative cover may be obtained by a small aircraft. Photographic coverage is usually obtained at 500 and 1000 ft. (150-300 meters). Plates 3, 4 and 5 are representative examples of this type of photographic data. Although light aircraft are readily available, such aircraft surveys for ground truth add to the complexity of the operation. There may, therefore, be a case for developing a short range platform of the Short Skyspy or Dornier Aerodyne type (plate 6) for use over ground truth test sites. One of the difficulties encountered in aircraft surveys is that of identifying with accuracy the points for which observations are required. A remotely controlled hovering platform directed from the ground would often be preferable and would aid the timing of observations.

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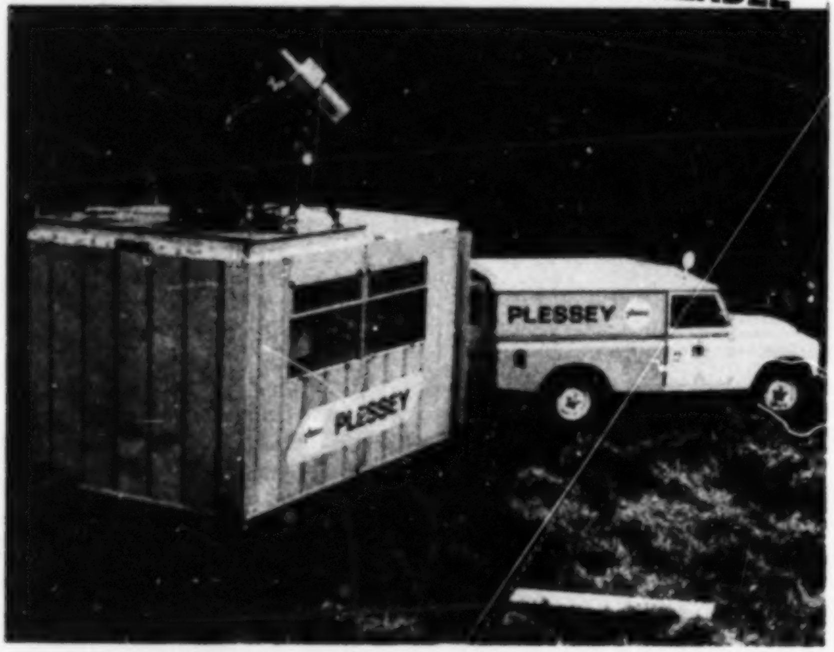

Plate 1. The Plessey reflectance spectroradiometer in use in the field. (Plessey)

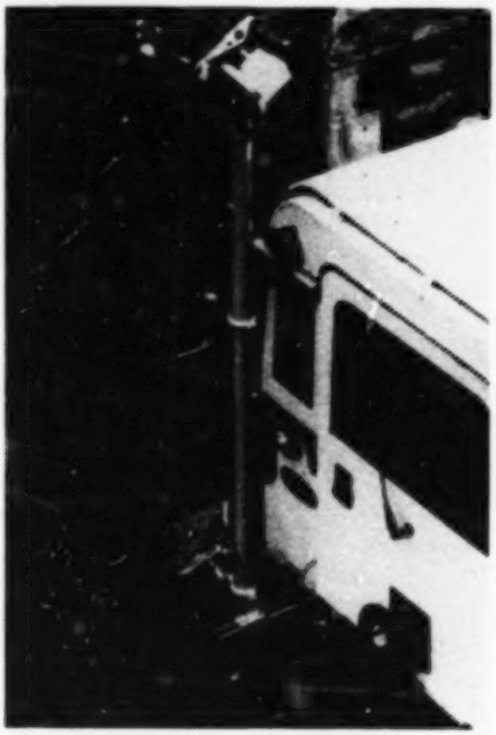

Plate 2. Spectrophotometer and camera mounted on mast for measurements in the visible parts of the spectrum. (Bristol University Department of Geography)

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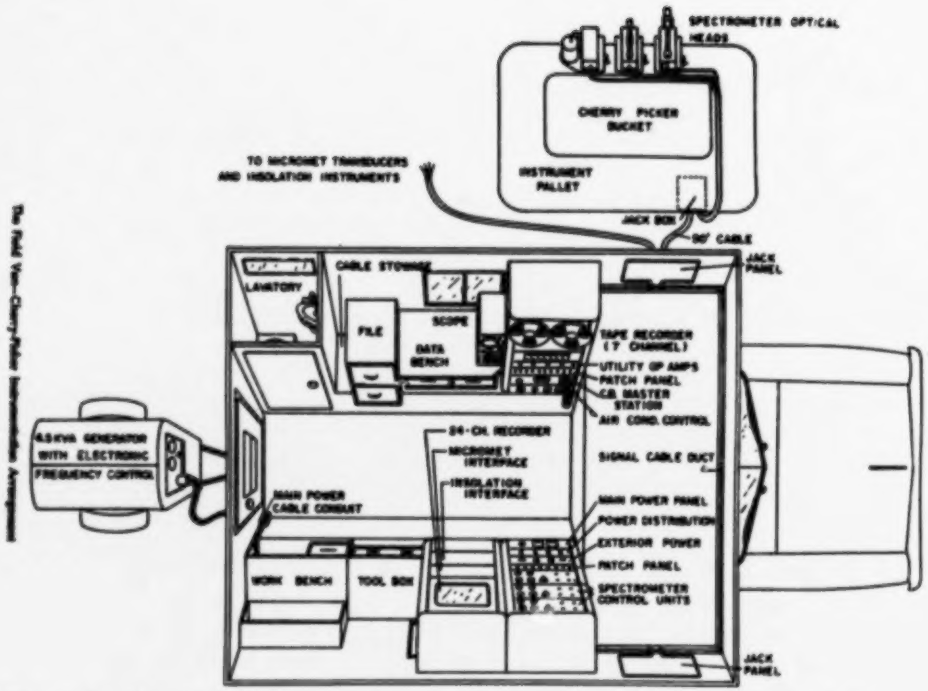

Fig. 3 Diagrammatic representation of the LARS cherry-picker observation platform. (Purdue University, USA.)

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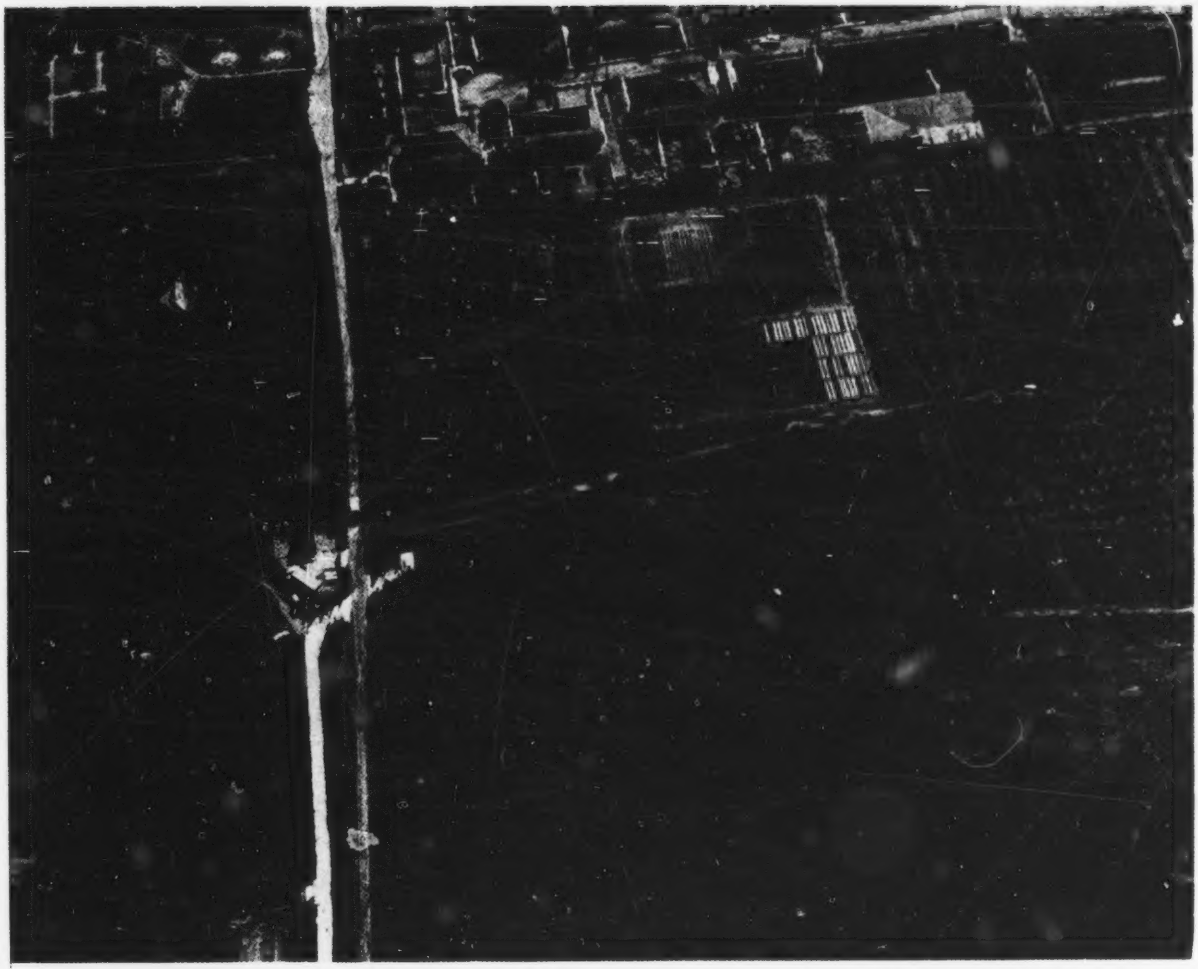

Plate 3. Panchromatic aerial photograph of a test site used by the University of Bristol to assess reflectance from soils and crops. Note the different appearance of areas of grass cut to different levels in a rectangle at the centre of the point. The tensiometer array shown in plate 7 can be seen above the rectangle as a light-toned line. The site is at Long Ashton, north Somerset.

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Plate 4. Colour photograph of the test site shown in plate 3. Note the clear distinction between different ages of growth of grass in the cut plots.

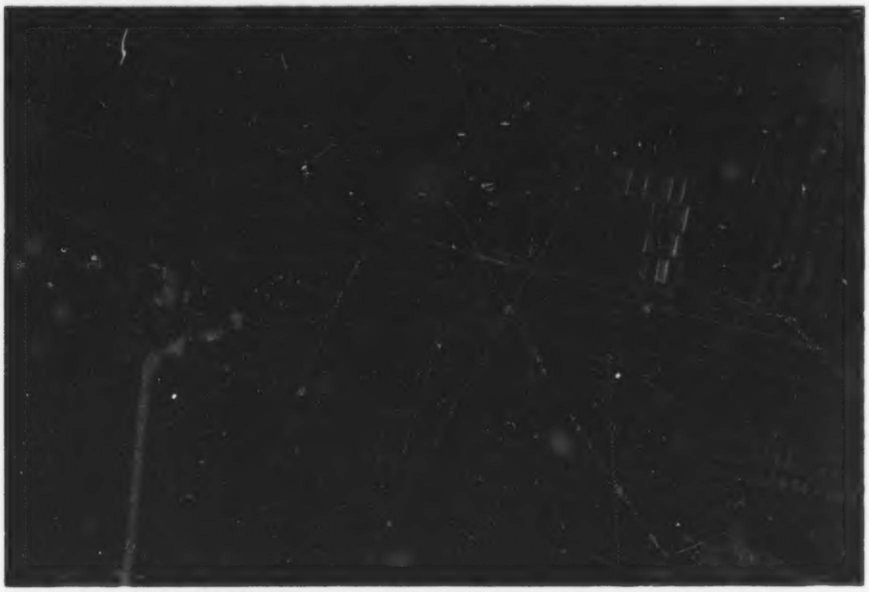

Plate 5. Infra-red colour aerial photograph of the test site shown in plate 3. Note the distinction between green grass and areas of dead grass in the cut-over plots. (Photo by T. H. Lee Williams)

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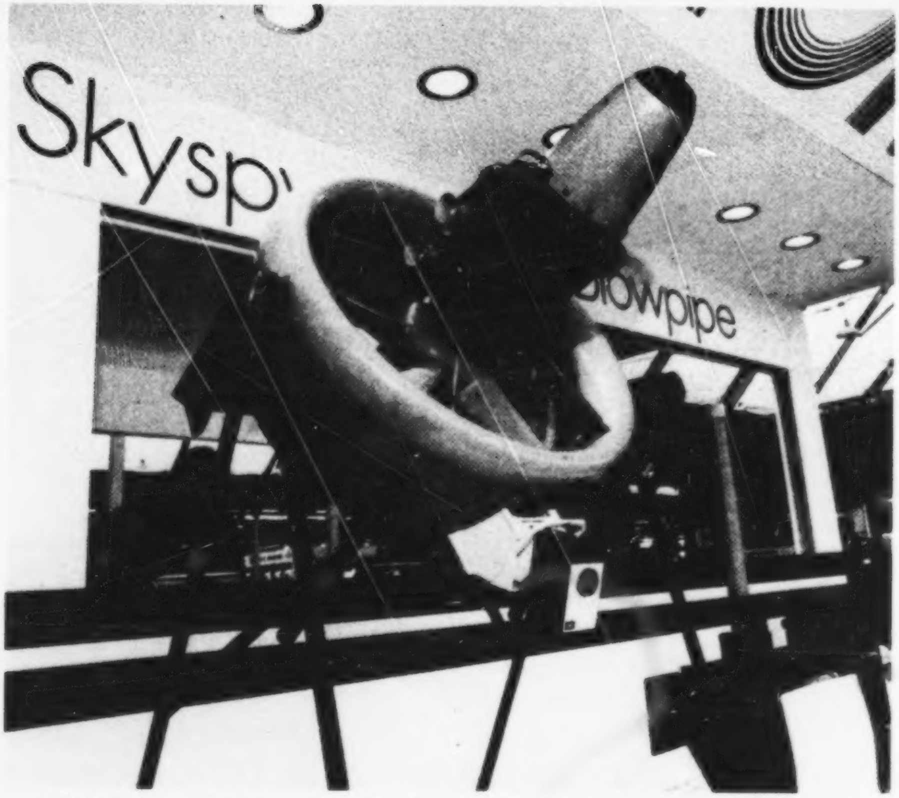

Plate 6. Photograph of the Short Skyspy drone platform. (Short photograph)

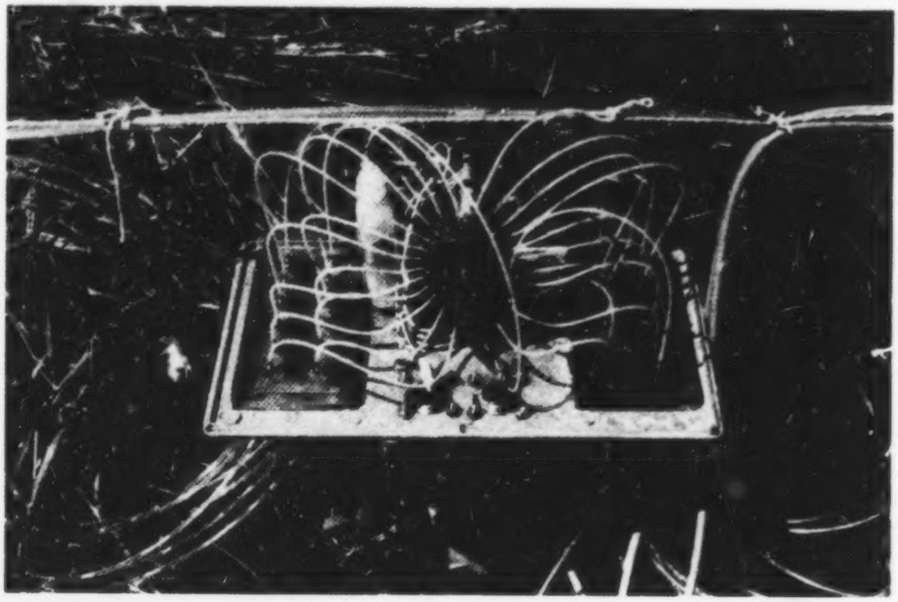

Plate 7. Close-up of the scanning valve system used in an automatic tensiometer array for soil-moisture measurement in relation to remote sensing devices. (Photo T. H. Lee Williams)

Identification of ground truth sites

It would seem that identifying the fields within a ground truth area would be a simple task. It is interesting, therefore, to note that both in Europe and North America field identification requires careful attention. In the U.S.A. farmers do not have fences around individual fields except in certain cases, e.g. separation of pasture from crop land. As a result, field boundaries are sometimes difficult to determine until crop growth is sufficient to distinguish one block from another. In Britian, the removal of hedgerows means that former field boundaries may disappear, thus making identification from maps more difficult. The LARS system of numbering is organized as follows:-

(1) Beginning in the north-east corner of the state each civil township is numbered in sequence throughout the entire state. Civil townships are large 6 mile x 6 mile squares, each of which contains 36 sections, each of which is one mile square.

(2) The position of a numbered section within the township is shown as follows:-

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

(3) Within each of the sections, individual fields are numbered. For example, the number 12 - 765 - 33 - 10 would indicate field number 10 of section 33 in township 765 located in state number 12.

Much of the European landscape is not arranged in such an orderly fashion but, in Britain, field boundaries can often be located on 1:25,000 map sheets. Thus reference numbers in British ground truth areas have been given on the basis of sheet number on which the field occurs and the field number along a traverse, e.g., ST^{88}/39(3).

GROUND TRUTH FOR SOIL STUDIES

Although it is convenient to consider collection of ground truth data for soil studies separately in this account, it is often the case that studies of remote sensing applications in agriculture require crop and soil data together. Indeed, many variations in soil conditions are best displayed by differences in the type of vegetation or crop vigour.

The range of soil data required in remote sensing studies includes morphology of the soil surface, soil taxonomic unit, soil moisture content, soil temperature, soil texture, soil structure, surface stoniness, organic matter content, soil color. General information concerning the description of soils in the field, can be obtained from technical publications of the soil survey of Great Britain (Soil Survey Staff, 1960) and U.S. Department of Agriculture (U.S.D.A. 1951). The following sections discuss the practices and problems of soil data recording from the standpoint of ground truth data requirements for remote sensing surveys.

The morphology of the soil surface is important since gradient, slope-form and aspect may have significant effects on sensor data. Normally, the altitude, aspect (orientation) and degree of slope of a soil surface can be readily recorded. The topology of the surface is, however, less easily described and terrain mapping techniques (Mitchell, 1973) must be employed which may be codified to suit computer records (Curtis, Doornkamp and Gregory, 1965).

The soil taxonomic unit should be recorded where soil maps of the area are available, in order that sensor data may be related to organized soil units. Normally, the sensor will be sensitive to textural and other variations within a soil series unit, i.e. the soil phase is the most appropriate taxonomic unit. If a soil map is available for the area, the record should include a note of soil phase or soil series (whichever mapping unit is used) together with the Great Soil Group in which the soil occurs.

Soil texture of the surface layers (0-20 cms.) determined by standard laboratory methods (Bouyoucos, 1951) can be reported according to the U.S.D.A. textural calsses (U.S.D.A. 1951). However, in the case of microwave sensors where some penetration of dry soils may be achieved, it is desirable that the texture profiles of the soils in the ground truth area should be recorded, i.e. textural classes occurring within a depth of 1 m. and the depths at which sharp breaks (if any) occur. Surface stoniness is best recorded by photographic records made by a hand held camera at waist level, using a size scale placed on the ground. The stoniness can then be given percentage values according to the scales of stoniness given in Clarke, 1957, or Soil Survey Manual (U.S.D.A. 1951)

Soil color has traditionally been recorded by the Munsell system (Smith, J. (Ed.) 1968). The difficulties of color matching for crops have been referred to above and, in the case of soils, problems arise because color varies according to moisture status and the nature of the surface examined. It is advisable to record colors in the dry and moist states on the faces of freshly broken soil aggregates. Studies by Parry et al, 1969, have shown that soil colors as recorded in the field and on aerial photography do not correspond; and overlap in hue, value and chroma is quite frequent (table 1). Indeed, one may question the usefulness of Munsell recording for remote sensing studies. It would seem better to develop an agreed-upon spectro-photometric recording system.

Organic matter content plays an important role in determining the color, consistence and structural characteristics of the soil surface. Baumgardner et al, 1970, have reported that organic matter plays a dominant role in bestowing spectral properties on soils when the organic matter content exceeds 2.0 per cent. Linear regression of organic matter content and wavelength response gave an r value of -0.74. Organic matter content was determined by the Walkley and Black (1934) method. This is a standard laboratory method but it should be borne in mind that, in some European soil studies, the methods of Rickson (1948) and Tinsley (1950) have been used.

Soil temperature is an important soil variable which is particularly important in remote sensing studies using infrared linescan and microwave radiometric sensors. The problem facing the investigator is how to measure the temperature of the uppermost layers of soil. If mercury-in-glass instruments are used the Penman brass strip technique (Penman, 1943) gives mean temperatures for the upper (1 cm.) layer; and bent stem soil thermometers can be used for the lower layers. However, such instruments require personal observation and do not lend themselves to automatic recording. Thus thermo-electric methods (thermocouple or thermistor) are preferable. Contact electric thermometers are also available for rock surfaces or gravelly soils (e.g. Wallac Contact Thermometer). Thermo-electric methods can also be used for measurement of leaf temperatures, and air temperatures (Landsberg, et al, 1973), the LARS studies have used "apparent temperature" measurements made with a Barnes PRT-4 radiometer.

If a remote sensor is integrating the temperature of a wheat field then a single ground truth measurement at a single point in the canopy will have little meaning. It is important, therefore, to install an array of sensors which can provide mean values for the crop area or soil area under review. Investigators should be aware of the fact that soil temperature data obtained by meteorological stations sometimes consists of measurements made by a mercury-in-glass thermometer suspended in air within a tube inserted into the soil. Clearly correlations between remote sensing measurements and such data are liable to be misleading.

Perhaps the most significant soil characteristic affecting sensor respon is soil moisture content. It is surprising, therefore, to find that remote sensing data obtained by technically advanced systems, sometimes carried by expensive space platforms, are compared to soil moisture data of doubtful validity. For example, Belyakova et al, 1971, reporting a study of microwave radiation from the satellite Cosmos 243 admit that "at most agricultural weather stations, the soil moisture content is estimated visually and expressed in arbitrary numbers which does not allow determination of absolute and relative moisture content of the soil." Thus the data available to Belyakeva was reduced to that available at those weather stations (about 30% of the total) where soil moisture was determined as a percentage of the dry weight of soil (gravimetric method, British Standards Institute, 1967). Soil moisture expressed as per cent of dry weight of soil has also been used by Kroll, 1973, in a study of remote monitoring of soil moisture using airborne microwave radiometers.

It is unfortunate that soil moisture data expressed on a dry weight basis has been used so frequently in remote sensing studies because comparisons between soils are then difficult to make. This is because the particle densities of soils may vary considerably (2.75 - 1.37) according to whether mineral or organic particles are present. The same amount of soil moisture in different soils can, therefore, give rise to different percentages of soil moisture when expressed on a dry weight basis. In view of this it is recommended that soil moisture data for remote sensing studies should be standardized, so that work in different areas of the world can be compared. In order to do this, it is preferable that soil moisture content be expressed on a volume basis. Thus -

$$\text{Per cent soil moisture} = \frac{\text{volume of water}}{\text{volume of soil}} \times 100$$

In order to determine soil moisture content in this manner, it is necessary to use a soil sampler (core sampler) of known volume. The volume of water is then determined by oven drying to 105°C as in the dry weight method. Providing the mass of a unit volume of soil is known, it is possible to convert from water contents on a mass (dry weight) to a volume basis and vice versa. The mass of a unit volume of soil is termed Bulk Density. Thus -

$$\text{Dry Bulk Density} = \frac{\text{Weight of dry soil}}{\text{Volume of dry soil}}$$

Field installation and sampling methods of measuring soil moisture can be divided into methods involving estimations of water content (by volume or weight basis) and methods for measurement of the energy (tension) by which water is held in the soil (Curtis and Trudgill, 1974). In many agricultural studies the tensiometric values are more meaningful because they most nearly reflect the soil moisture available to plants. It is advisable, therefore, to include a tensiometric measuring system in the field installations for ground truth sites. Initially, such measurements were obtained by reading individual tensiometers. Recent developments by the Institute of Hydrology include the development of a system of ten tensiometers recording soil moisture tension on a Microdata logger (Natural Environment Research Council, 1974) and simple automatic logging systems developed by the University of Bristol (plates 7, 8).

The neutron scatter method of determining moisture content has been employed by Purdue University, where a Troxler Neutron Surface Probe was used (LARS, 1967). A Wallingford Neutron Probe (plate 9) has been used in

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Plate 8. A linear array of tensiometers for soil-moisture measurement at a ground-truth site at Long Ashton, Somerset. See also plates 3-5 for aerial views of the site.

Plate 9. Making soil moisture measurements with the Wallingford neutron probe at a test site near Bristol.

British remote sensing studies (Curtis, 1974) but the main constraint in the use of such probes is that of providing manpower. However, the Institute of Hydrology has developed an automated version of the Wallingford probe which can be left unattended for a month or more at a time. It will scan the soil profile at pre-set depth and time intervals, logging the output on a modified Microdata logger. Each measuring cycle takes about 15 minutes, assuming that ten stations are read with 64-second counting times. The development of an automated neutron scatter system will be of great assistance to investigators setting up ground truth sites. It should be remembered, however, that careful calibration of the probe in relation to the soil in which it is used is necessary if meaningful comparisons are to be made between soils at different sites. For a further discussion of soil moisture measurement in the field, see Curtis and Trudgill, 1974.

Soil structure (aggregation of particles) is, perhaps, the most difficult soil characteristic to quantify. Nevertheless, the structure (aggregation) of a soil is an important feature in relation to sensor response. The structure largely determines the roughness and tilth of a bare soil. It also has a considerable influence on the distribution of water and temperature within the soil. Although the types of structure present can be described by standard methods (U.S.D.A. 1951) what is usually required is a measure of the roughness of cultivated field surfaces. Attempts have been made to determine this by sieving surface aggregates and determining percentages of different sizes. However, this is time consuming and is subject to considerable error where weakly structured soils break down on sieving. An alternative measure of surface roughness may be provided by wind profile measurements near the ground using the principle that the greater the roughness the greater will be the drag and turbulance near the ground (Lettau, 1969; Thom, 1972). Experiments, using this approach, are worthy of consideration by remote sensing scientists.

A useful indication of the micro-aggregation of soil particles is given by Bulk Density (volume/weight) determinations. Unlike particle density, which is concerned with the solid particles only, bulk density is determined by the quantity of pore spaces as well as solids. Soils which are well aggregated usually show relatively low bulk densities (C.0.4/gm/cc.) whereas compact soils may have bulk densities as high as 2.0 grms/cc. or higher. Where microwave sensors are used, bulk density measurements may be particularly relevant to the interpretation of the data.

SELECTION OF GROUND TRUTH SITES

The location of areas for ground truth data collection will be decided upon the basis of criteria such as study objectives, sample size satisfactory for statistical purposes, repeatability and continuity of the experimental study, access to the study area, availability of personnel and equipment resources. Of these, the study objectives impose a major constraint, e.g.

studies of irrigation agriculture must be carried out in areas where such agriculture is practiced. Also, in satellite studies, the orbit characteristics of the satellite platform may place such constraints on the repeatability (i.e. interval between observations) of the experimental study that many otherwise suitable sites are excluded.

The shape of the ground data collection area is dependent upon statistical requirements, speed of access by ground teams and swath widths of the sensors employed. The allocation of sample plots in a data collection area is made more statistically efficient if the area can be stratified into relatively homogeneous areas e.g. - grassland, arable, woodland, etc. For stratification to be useful, strata boundaries should separate areas where within class variance is less than between class variance (Webster and Beckett, 1968; Beckett, 1974). There is a case, therefore, for the operational user to be involved in decisions concerning the shape of ground truth areas in terms of the variables which are significant to him.

The size of the ground data collection area will be affected by study objectives, sensor swath width, statistical considerations, scale of phenomena and the time interval between observations that is allowable. In general sensor testing will require small ground truth sites which can be observed frequently, inventory studies may require larger ground truth sites to allow collection of a sufficient number of examples of the crop/land use conditions under study. In crop and land-use studies, a common requirement is that the observations should be related to the crop calendar of the area concerned, and there is a general need for crop calendars to be available, at least regionally (Freden and Mercanti, 1973).

One of the most widespread problems facing investigators is that of obtaining ground truth data which is contemporaneous with the overflight of the area (LARS, 1968; Curtis and Hooper, 1974). It is desirable, therefore, that the size of ground truth sites should be the minimum consistent with adequate sampling of the variables concerned. The development of automated ground data recording systems is an urgent requirement in order to ensure that expensive satellite experiments are adequately supported by ground truth data. In the case of land and soil studies, the variability of the surface conditions both spatially and temporally demands that automatic recording systems should be available in (i) mobile (vehicle based) and (ii) static (data collection platforms) forms. The development of the Post Apollo programme, including the Spacelab missions scheduled for 1980 (Cassinis et al, 1973) will require extensive ground truth monitoring. The need is urgent, therefore, for the application of space technology to ground based platforms as well as satellite systems.

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EARTHQUAKE HAZARD ZONES IN PART OF BALUCHISTAN, PAKISTAN

By M. S. **Hasan**
Geological Survey of Pakistan

ABSTRACT

Capable faults in parts of Baluchistan were delineated by use of satellite imagery. The traces of the Chaman-Nushki and the Ornach-Nal faults were mapped. A new active fault system was detected. The new fault system has been designated the Quetta-Mastung-Surab fault system. Historic records of the last 70 years show that the seismicity recorded in the region has been associated with this fault system.

INTRODUCTION

Scope of the report

Landsat imagery along one orbital path of the satellite over Pakistan was interpreted to delineate the traces of capable faults in parts of Baluchistan. The information was extracted from four frames and compiled in the form of a map showing the capable faults. Recognition in the data that the trace of a fault cuts Recent and sub-Recent alluvium was used as a guiding factor for determining the capability.

The data on faults previously mapped and the seismological data of the area for the last 70 years has been reviewed in the context of plate tectonics.

The Landsat imagery had been acquired along one orbital strip over Pakistan, commencing at 31° N., 67° E. as the centerpoint of the northernmost scene, February 19, 1975, and again on June 7, 1975. Scene centerpoints, dates, and formats employed were as follows (Scale 1:1,000,000):

Center coordinates	Date	Format
N. 30° 05'; E. 66° 43'	June 7, 1975	Positive transparencies in MSS bands 4, 5, and 7.
N. 28° 40'; E. 66° 19'	-do-	-do-
N. 27° 14'; E. 65° 55'	-do-	-do-
N. 30° 05'; E. 66° 50'	Feb. 19, 1975	Black and white prints in bands 4, 5, 6, and 7.
N. 28° 43'; E. 66° 26'	-do-	-do-
N. 27° 17'; E. 66° 02'	-do-	-do-
N. 25° 51'; E. 65° 38'	-do-	-do-

Three color composite transparencies were prepared from 1:1,000,000-scale positive transparencies on a Diazo processing maching, using yellow film film for MSS band 4, blue for MSS band 5, and red for MSS band 7.

The color composites were studied on a light table with the help of a magnifying glass. The linear features that could be interpreted as faults were plotted on overlays. One color composite with center coordinates N. 27° 14'; E. 65° 55', prepared from imagery taken on June 7, has partial cloud cover. The shadows of the clouds on the ground obscured details. Black and white prints were studied on the light table under a magnifying glass. The overlays prepared from the analysis of the color composites were superimposed on black and white prints of imagery taken on February 19. The results were checked. Information for areas of the gaps left because of cloud cover in the June 7, 1975 scene was obtained by analysis of the February 19, 1975 scene. Four overlays of linear features thus prepared were superimposed on the 1:1,000,000-scale base map by the Geological Survey of Pakistan. The changes in the coastline which had occurred since the map was prepared in 1936 were corrected with the help of black and white prints. MSS band 7 offered the best contrasts among dry soils, moist soils, and water bodies along the coast.

CAPABLE FAULTS OF PARTS OF BALUCHISTAN

Landsat imagery proved to be useful for delineating the traces of capable faults and their relationships. The synoptic view and the distinction of details on the basis of moisture and vegetative patterns in different spectral bands were quite helpful in interpreting the presence of capable faults along those segments where they cut Recent alluvium. The linear features seen in the alluvium are at present marked by small streams, or by vegetation, or have slightly raised ground on one side. Such features, where they are in conformity with the traces of faults in hard rocks, have been marked as capable faults (fig. 1).

The traces of faults are shown on the map. Two categories of faults were distinguished. These are (i) inactive faults and (ii) capable faults. The inactive faults have been mapped but are not discussed in this report as it would involve the discussion of detailed geology of the area which is beyond the scope of present report. Among the capable faults, three systems of faults have been distinguished and are described below:

Chaman-Nushki fault system.-- The trace of the Chaman-Nushki fault was delineated for a distance of 330 km starting from where it enters Pakistan from Afghanistan east of Chaman, southward to a location northwest of the village of Besima. The fault trace has a north-northeast trend and appears

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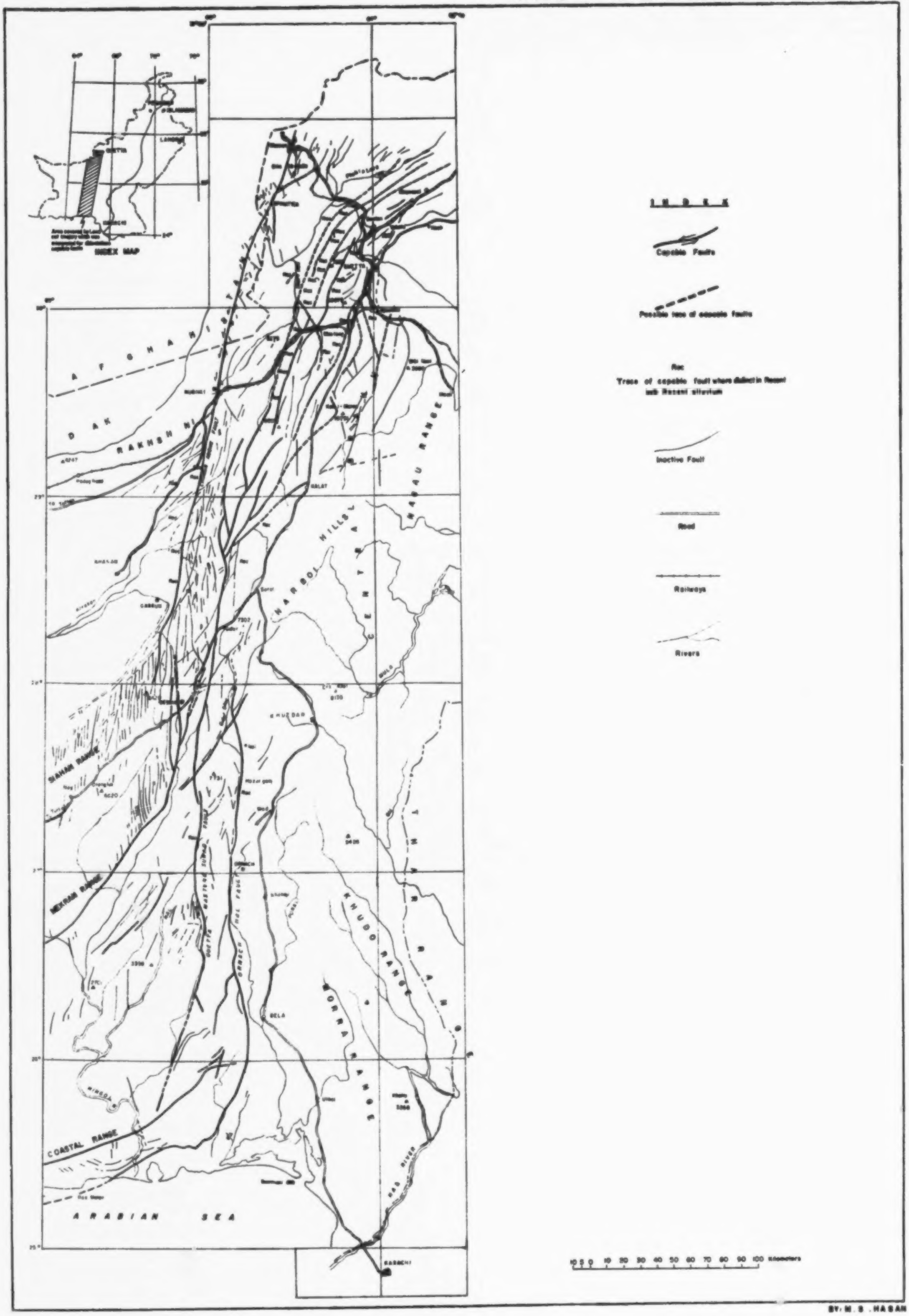

BY: M. S. HASAN

Figure 1. Map showing capable faults of part of Baluchistan, Pakistan.

distinctly on the satellite imagery throughout this length. The trace is not clear farther south of Besima village. The trace is distinct in Recent and sub-Recent deposits, as well as in areas of hard rock. Streams offset in a left-lateral pattern could be noted. The fault is concave toward the northwest to the north of Spinatiza and is concave to the east in the segment from Spinatiza to Carruk village.

The fault trace extends north into Afghanistan for a distance of about 500-600 km up as far as a location near Chirikar village (Farah, 1976).

Most important structural intersections along the fault are in the north and south of Spinatiza village. The seismic record over the past 70 years shows that the northern segment from Chaman to Nushki is seismically more active than the southern segment. During an 1892 earthquake (Grieshbach, 1893), the seismic activity was centered around the old town of Chaman where cracks and fissures developed. During an October 1975 earthquake (Farah, 1975), cracks and fissures developed in the vicinity of Spinatiza village.

Ornach-Nal fault.--The trace of the Ornach-Nal fault was delineated for 330 km starting at the sea coast and continuing northward to a location to the north of Nal village. The trace of the fault appears quite distinctly in the Recent and sub-Recent deposits south of Nal village. The trace of this fault farther north is not distinct.

This is a capable, left-lateral fault on which the western side moved up (H.T.S.C., 1960).

Quetta-Mastung-Surab fault system.-- The most important delineation made from study of the satellite imagery is that of the Quetta-Mastung-Surab fault system. This fault system is the youngest in the region and appears to be the outcome of differential movements along the Ornach-Nal and the Chaman-Nushki fault systems. The trace has been delineated form the coastal range near the Hingol River northward to a position northeast of Quetta--a distance of more than 580 km. The fault trace trends north to the northwest of Surab. At a location of 27 km mortheast of Surab, branches trending northeastward have developed. These branches become parallel with each other to the north. The traces of these faults are distinct in hard rocks. In sub-Recent and Recent alluvium they appear to be faint lineations. Field checks have not yet been made to prove that these are active faults. However, the seismic record (Farah, 1976) over the past 70 years shows that most of the seismic activity is associated with these faults. Most of the earthquakes were registered at magnitudes of 6 to 7.7 on the Richter scale, with focal depths from 0 to 50 km; a few with focal depths from 51 to 100 km have been recorded in this region.

DISCUSSION OF THE CAPABILITY OF FAULTS

CONTEXT OF PLATE TECTONICS

The Chaman-Nushki and Ornach-Nal faults have been inferred to be the remnants of a megashear which might have existed prior to the collision of the Indo-Pak plate with Asia. The time of collision has been considered to be Eocene (Powell and Conaghan, 1973, 1975; Stonely, 1974; Molnar and Tapponiar, 1975; Wensink, 1975). After the collision the consumption of the Indo-Pak plate produced crustal shortening of 1500 km (Molnar and Tapponiar, 1975; Powell and Conaghan, 1973, 1975). Because of this crustal shortening, the whole of the Indo-Pak continent must have moved about 1500 km northward since the collision. It is assumed that a movement of this order should have occurred along the megashear after the collision. Several thousand feet of stratigraphic displacement has been reported (H.T.S.C., 1960).

Wensink's (1975) findings based on magnetic anomalies discovered by Heirtzler et al (1968), McKenzie and Sclater (1971), Fisher et al (1971), Laughton et al (1968), and Sclater and Fisher (1974), indicate that after collision of the Indo-Pak plate with Eurasia there was no spreading along the Carlsberg Ridge during the period from 55 m.y. to 35 m.y. ago. The mid-Indian ridge did not exist at that time. The mid-Indian Ridge began forming 35 m.y. ago. The rise of these two ridges has not been equal. From the record of magnetic anomalies for the last 0-10 m.y., a rise of 1.1 cm/year is calculated for the mid-Indian Ridge, and of 0.6 cm/year for Carlsberg Ridge. Over the last 10 m.y., the addition of sea floor area in the Arabian Sea has been less by 0.5 cm/year per flank than has been the increase of sea floor area of the Indian Ocean. This resulted in the development of counter-clockwise rotational forces in the Indo-Pak plate. The effect of the resultant counter-clockwise rotational forces accompanied by the northwest drift of the continent was the dislocation of the southern segment of the megashear and offset toward the east in the vicinity of Hazargangi. This process may safely be predicted to have started about 10 m.y. ago. After the offsetting of the Ornach-Nal fault toward the east, the tectonic activity along Chaman-Nushki fault became confined to the northern segment only. The tectonic activity in the south remained with the offset remnant, namely the Ornach-Nal fault.

The new, younger faults of the Quetta-Mastung-Surab fault system developed between the Chaman-Nushki and the Ornach-Nal faults, to accommodate the tensional and compressional stresses being caused by rotational and drifting forces. The new fault system follows a north trend from the Coastal Range to a place 27 km northwest of Surab. At this location, several branches trending northeast have developed. These faults became parallel to the northeast and follow the Quetta syntaxis (H.T.S.C., 1960). The tectonic stresses accumulating in the Ornach-Nal fault and Chaman-Nushki fault are released through these younger faults.

The seismic record over the last 70 years indicates that a number of earthquakes of magnitudes of 6 to 7.7 on the Richter scale, and having focal depths from 1-50 km, have been associated with these younger faults. A few of the earthquakes had focal depths of 51-100 km. It is, therefore, inferred that the areas in which the traces of these newly defined faults appear are hazardous.

CONCLUSIONS AND RECOMMENDATIONS

Landsat imagery proved to be a useful tool for delineating the traces of capable faults. Knowing the locations of capable faults and the magnitude of earthquakes, their focal depths, and the locations of their epicenters, once can calculate and provide to engineers responsible for construction and development work in hazardous areas the values of ground acceleration ("g") that might be expected.

Landsat imagery should be used for the delineation of active faults in the Regional Countries. The traces of all observable faults should be measured, and their locations related to the highest magnitudes of earthquakes recorded in the areas of their influence. Then, based on the values of "g" calculated for different areas, an earthquake hazard map of the Regional Countries can be prepared.

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APPLICATION OF REMOTE SENSING IN MINISTRY OF AGRICULTURE AND NATURAL RESOURCES OF THE IMPERIAL GOVERNMENT OF IRAN

By Informatics and the Remote Sensing Division
Ministry of Agriculture and Natural Resources

INTRODUCTION

The agriculture, forest, and rangeland resources of Iran are presently the subject of large-scale, intensive development programs. Several studies have been undertaken in the Ministry of Agriculture in recent years to determine the best strategy for allocating land use between agricultural crops, pasture grasses, and forest lands. As remote sensing appears to be the best and most appropriate technique and methodology available for an extensive survey on a national basis, the studies for determination of an optimum balance of land use will be completed by means of remote sensing technology.

Projects have been undertaken to 1) define a computer-based system for crop forecasting that would capitalize on the computer capability for assembling and integrating all available data, including that from remote sensor systems, and 2) develop procedures for mapping forest types and soil types using Landsat data. This paper reports on results of these projects and on an aerial survey project for forest type mapping.

In the following the outline of the main projects to which the remote sensing technique has been applied, together with plans for training and equipment acquisition, are explained.

CROP FORECASTING AND PRODUCTION ESTIMATE

Assessment of import needs and export potential for various agricultural commodities is an important function of the Ministry of Agriculture and Natural Resources. This function, to be successful, requires accurate and timely prediction of agricultural crop production. Current statistical sampling techniques do not provide the timeliness needed; even though planted hectarage is well known, the subsequent influence of weather and other stress-inducing factors on yield cannot be determined by traditional methods.

Recognition of limitations inherent to current statistical sampling techniques influenced a tentative decision by the Ministry of Agriculture to initiate research into techniques and procedures needed to develop and implement a dynamic crop-forecasting system within the 5-year period 1975-79, with the following characteristics:

- Accurate and timely crop estimates
- Highly automated where practical and economical
- Known error characteristics
- Failure resistant
- Sensitive to all production variations
- Capable of expansion

The system will make the best use of the present sources of information derived from data collected by the statistical services of the Ministry and will in addition make full use of the Earth Resources Technology Satellite, Landsat (formerly designated ERTS), various Meteorological Satellite data (METSAT), and other remote sensing data-collection systems, including aircraft and the currently planned and approved research satellites of the National Aeronautics and Space Administration (NASA) of the United States Government.

The system will use the latest agronomic and agrometeorological forecasting models as well as the most modern statistical sampling methods. The specific objectives of the system are as follows:

a. The analysis, documentation, and systemization of the current crop forecasting procedures now in use, and the determination of the ways in which existing data sources can be of use to support both the models that will be developed and the remote sensing data that will be used (the Subjective Yield Model).

b. The conversion, development and application of a complete system of computer software packages to be used for the determination of crop hectarage using remote sensing data (the Hectarage model).

c. The conversion, development, and application of a system of agrometeorological models and computer programs to be used for crop yield estimates (the Agromet Models).

d. The development of all necessary crop calendars, crop distribution data, and agricultural practices data needed to establish complete crop phenology records to be used for agronomic yield estimates (the Agronomic Model).

e. The development of all necessary data on weeds, plant pests including both insects and disease, and all data on control efforts, herbicide and pesticide applications, and management practices (the Stress Model).

f. The design and implementation of the surface observations and measurements, and aircraft support programs required to make the most effective use of the satellite data (the Remote Sensing Model).

g. The development, for each major crop of interest, of the numerical equations related to total production and the sampling models appropriate for the situation in Iran, that will minimize estimation errors of crop production and at the same time minimize the cost of sampling, both from satellite and collateral data sources (the Statistical Model).

h. The development of the integration equations specific for Iran which aggregate and weight each of the models, including their basic inputs, as a function of the actual field data collected during the season, and which will be capable of performing a sensitivity analysis, from one growing season to to next, of those factors which exercise the greatest influence on yield in Iran (the Objective Yield Model).

Status

The general program is in an early stage of development, but a significant amount of work regarding the components of the initial development phase of the crop forecasting program has been accomplished, as follows:

- Data management and display
- Agrometeorological data and models
- Ecological partitioning
- Agricultural area determination
    - Historical statistics
    - Manual and automated analysis of Landsat data for area determination
- Crop yield determination
    - Historical statistics
    - Crop phenology
    - Soil capability
    - Yield model development

Each of these components will be briefly described.

DATA MANAGEMENT AND DISPLAY

Dynamic crop-forecasting systems with repetitive data input from ground reporting stations, meteorological satellites and earth resources satellites require a computer-oriented data management system. Such a system provides an automated method of assimilating, storing, combining, and retrieving all data that relate to crop forecasting as specified by any potential user. This method has become a major tool for planners and managers because it provides a means of automatically combining environmental, phenological, and meteorological data.

A developmental data management and display system has been designed for the entire country of Iran. The base for this system is the 20x20 kilometer agro-met grid-cell network, the utility of which has been tested with agronomic data, meteorological data, and historical data.

Displays have been developed in three formats: printer display, X-Y plotter (CALCOMP) displays, and photographic displays. The X-Y plotter and photographic displays offer the capability of combining administrative boundaries, ground sampling points and the agro-met cell network with other data display.

The basic grid is rectangular with a spacing of approximately 40 km. The grid network is divided into cells 20x20 km in size, with four cells surrounding each of the 40 km grid network points. The grid network and cells are stored in the computer as an I, J, K matrix. The array of grid points and cells can be addressed as either a computer (I,J,K) matrix or referenced by latitude/longitude description.

The grid cell network has been defined and tested for a variety of different data storage, retrieval, and manipulation processing activities. Meteorological interpretations from met-sat data (e.g., cloud cover and cloud type) have been assigned to the grid cell network for the entire country for the period from July 1, 1973, to July 31, 1974.

The grid cell overlays were also used to assign other parameters to the computer grid cell matrix, including:

- Soil capability classes associated with agricultural lands.
- Percent agricultural land by grid cell for a portion of the country using the Landsat mosaic and selected individual Landsat scenes.
- Political boundaries (ostans) for the entire country.

AGROMETEOROLOGICAL DATA AND MODELS

Plant growth and agricultural yield are controlled in part by weather conditions. It is therefore important to gather historical weather information as a basis for future evaluation of the relationships between meteorological parameters and crop yield. The necessary information has been extracted from the meteorological yearbooks (1956-1964) and the monthly weather summaries (1970-72) of the Iran Meteorological Department. Climatological data for a total of 17 years (1956-1972) have been punched on approximately 10,000 cards and recorded on tape.

The meteorological data-gathering activities emphasized those parameters which are applicable in a crop forecasting program: precipitation, maximum and minimum temperatures, wind, relative humidity, and cloud cover.

In addition to these data collected for the synoptic meteorological stations, climatological and rain-gauge station data on precipitation have been collected for the period from 1956 to 1964. The historical data have been used to develop transformations that relate to plant growth and yield. This data base is used to calculate the following parameters:

-Net radiation (RNET)
-Potential evapotranspiration (ETP)
-Degree days
-Day length
-Soil moisture content

In addition to the assembly and formatting of the working data base, a number of other activities have been accomplished in areas relating to agrometeorological modelling. These include:

-Assembly of a 1973-74 cloud cover file in computer compatible form derived from satellite ovservations over Iran.
-Development of grid point precipitation mapping routines which use the computer compatible satellite data.
-Partitioning of Iran into climatic zones for spreading precipitation data from the 43 synoptic stations.

ECOLOGICAL PARTITIONING

In a country as complex and diverse as Iran, successful crop forecasting requires that the environment be partitioned into areas that are more homogeneous than the country as a whole. The hierarchy of natural regimes in a landscape provide a better basis for monitoring and sampling agricultural activity than do arbitrarily assigned political units. Preliminary criteria for ecological zoning of Iran into regions of homogeneous crop production characteristics have been selected and have produced the following products:

-A tentative macro-regionalization for the entire country using the Landsat mosaic of Iran as a base
-A sample micro-regionalization completed for a single Landsat scene which contains the area around Tehran and a part of the north of Iran

The environmental factors which were employed for ecological partitioning include: regional distribution of land forms, geology, meteorology and climatology, hydrologic features, and human activity.

AGRICULTURAL AREA DETERMINATION

A major objective of this phase of the project has been the development, inplementation, and evaluation of techniques for the determination of agricultural areas. Primary efforts include acquisition of image materials and evaluation of various visual and automated techniques for deriving crop area information.

Accurate determination of the area occupied by each crop type in a crop-forecasting program is a task that can make effective use of various types of remotely sensed data. In this phase, emphasis has been directed to defining effective techniques and procedures for utilizing Landsat data to provide an initial estimate of total agricultural land per grid cell. These activities have included:

- estimates based on visual interpretation of the Landsat mosaic of Iran.
- estimates based on visual interpretation of Landsat color-composite images acquired at more optimum dates than the images comprising the mosaic.
- estimates based on visual interpretation of selected computer-enhanced images.
- estimates based on electronic data processing and several different multispectral classification techniques on selected scenes.

A series of tasks have been performed to evaluate the utility of Landsat digital image data for determining the percentage of agricultural land. The objectives of these tasks were to:

- Develop techniques to merge digital Landsat data with that of the agro-met grid to provide input to the data-management system.
- Evaluate the capability to accurately determine percentages of agricultural land from digitally enhanced imagery.
- Evaluate various algorithms for classification of multispectral data for accurate determination of agricultural land.

The study of multispectral data processing evaluated the applicabilities of two programs, LARSYS and CLASSER, for identification of agricultural land use. Results of the study indicate that 74.9 percent (area 1) and 92.6 percent (area 2) of agricultural land-use classes were correctly identified in the test areas with LARSYS. The CLASSER program offers a potentially fast and less expensive classification than LARSYS, but the accuracy of the system was less than that of the LARSYS.

CROP YIELD DETERMINATION

Historical crop-yield statistics

A variety of yield data for wheat as well as for other crops has been collected. With respect to wheat yield, the following data have been gathered:

Year	Type of data	Level of aggregation
1350 (1971) and 1339 (1960)	Production and yield (irrigation and non-irrigation wheat)	ostan
1346-52 (1967-73)	Production	ostan
1337-50 (1958-71)	Production	entire country

Crop phenology

Crop calendar data have been analyzed for the Shahrestans for which reports were available. These calendars contribute to yield determination in two ways. They are suitable for deriving median planting and harvest date information for each 40 x 40 km agro-met grid cell. In addition, they provide a basis for selecting the optimum seasonal periods for monitoring crop status with remote sensing techniques (Landsat and aircraft).

Soil capability analysis for crop forecasting

For crop forecasting purposes, mapped soil categories are most useful when they reflect the relative capacities for crop-available-moisture; for this reason, the legend of the existing soils map of Iran was reorganized so that the new categories conveyed this information. Consequently, the major soil types of Iran have been classified according to their moisture-holding capacities. Five general classes have been established. The soil data, taken from the soil map of Iran, have been coded into the data base according to this classification.

The process of determining crop-available moisture factors from soil information and adapting them to the Iran crop forecasting program is outlined in the following sequence of tasks:

1. Locate best available data sources
   Sources available for this task included:
   -Original Landsat mosaic of Iran
   -Selected digitally enhanced Landsat frames
   -Selected black and white Landsat enlargements
   -Soil map of Iran
2. Prepare working transparencies of soil map and agro-met grid

3. Establish crop-available-moisture classes
4. Prepare new soil map
5. Determine dominant crop-available moisture-class for each agro-met cell
6. Code data for storage and retrieval

DATA PROCESSING AND ANALYSIS SYSTEM (EQUIPMENT - FACILITIES)

Remotely sensed information comes to the Ministry of Agriculture and Natural Resources from a variety of sources. International programs, such as the Landsat, SKYLAB, and METSAT programs, will provide data on films, on magnetic tapes, and by direct satellite transmission. Aircraft programs within Iran will also provide photographic camera and radar data, from low-, medium-, and high-altitude surveys.

The Informatics and Remote Sensing Central needed to establish the equipment, procedures, and support functions to make effective use of these data, and to make them available for a variety of applications. Therefore facilities are being established for a powerful digital-image-processing center together with photointerpretation facilities and airborne-data-gathering systems. The following laboratories are already established:

-Analog equipment system
-Digital image processing system
-Photographic laboratory system

After critical study and economical evaluation of systems available in the market, proper equipment has been purchased and installed. In order to use the hardware systems for all the remote sensing processes in crop forecasting, the following software has been developed:

Geometrical correction:

-To geometrically correct for the 3 to 2 aspect ratio inherent in all Landsat data and to remove the distortions introduced by skew resulting from the rotation of the earth relative to the satellite during the exposure. The image may also be rotated to true North during this operation if desired.
-To perform an arbitrary scale change on an input image.
-To geometrically register two images. In this operation, a user-specified set of control points is used to define the required geometric transformation. A third-order polynomial in x and y plus the reciprocal terms 1/x, 1/y, and 1/xy is fitted to the user-specified control points to define the geometric transformation required to register to two images.
-To rotate an image by an arbitrary angle in the plane of the image and to perform rotations to correct for roll, pitch, and yaw.
-To apply a spatial warping to an image by fitting a polynomial function to a set of user-defined control points defining the desired transformation.

-To provide a user-selectable resampling option between nearest neighbour and linear interpolation for all geometric operations.
-To transform Landsat MSS imagery to the Space Oblique Mercator projection.
-To transform an image to the UTM projection.
-To perform geometric correction for platform errors on Landsat MSS imagery when platform information is available.

Radiometric correction:

-To perform histogram equalization (redistribution) on data to enhance an image.
-To impart a piecewise-linear intensity to an image. User must specify the breakpoints.
-To automatically scale an image linearly into a user-defined intensity range.
-To compute the logarithm of each pixel value in an image.
-To compute the exponential value of each pixel in an image.
-To compensate for the radiometric differences between two images obtained at different sun angles. The user specifies the two sun angles and the image which is to be corrected.
-To adjust the gain and offset of the data collected by each of the six elements of each sensor bank of the Landsat MSS, to reduce the effects of banding.

Spectral ratioing in order to remove noise and to normalize the intensity levels of images.

Arithmetic:

-To compute the weighted algebraic sum of all input images. The user may select signed weighting factors at execution time.
-To compute the products of input images on a pixel-by-pixel basis.
-To compute the quotient of two images on a pixel-by-pixel basis.

Image transformation:

-To perform the two-dimensional discrete Fourier transform on a real-valued image.
-To perform the inverse discrete Fourier transform on a transform image.
-To perform a one-dimension Hadamard transform on a real-valued image.
-To perform the one-dimensional Fourier transform on the spectral or temporal dimension of an image.

- To perform the Karhunen-Loeve transform on the spectral or temporal dimension of an image.
- To compress the image size by computing to Karhunen-Loeve transform of each n by n subblock in the image and retaining only the principle component. For this application the value of n must be between 2 and 10.
- To compute the subset of channels which maximizes the transformed divergence of the input training sets.

Spatial filtering:

- To generate and apply a general exponentially shaped frequency domain filter operation.
- To generate and apply a Gaussian frequency domain filter operation.

Satistics:

- To compute the histogram of an entire image or any rectangular shaped sub-area.
- To compute and deliver to the user the minimum, maximum, mean, and variance values of an image.

Data conversions:

- To digitize images
- To generate film transparent images of scenes

General utilities:

- To perform image compression by averaging over a rectangular area to compute new output values for pairs or groups of pixels.
- To mosaic.
- To insert one picture into another to form a new image.
- To modify an image data set to create a new image by employment of functions noted above on digitized values.
- To transpose any two dimensions of an image.
- To create a multiband or multitemporal image from any number of input images.
- To generate an image whose pixel values are functionally related to pixel locations in the image.
- To generate an image whose pixel values are linear functions of their distance from a user-specified point.

Classification:

For classification and interpretation of satellite data, software has been developed:

- To perform unsupervised classifications using an iterative clustering algorithm.
- To perform supervised classifications using a maximum likelihood classifier with a quadratic decision rule.
- To perform supervised classification using a parallelepiped classifier.
- To select and synthesize image information to create training sets for use with supervised classification.

Preparation of the Caspian Forest Type Map

A topographic map of the Caspian Forest area is being produced at the scale of 1:250,000. In this project, started in 1971 and to end by 1976, aerial black and white photographs of scale 1:25,000 have been used in a photogrammetric process.

A part of the project involves preparation of a forest type map, to be superimposed on the topographic map sheets. For this reason, development of a photointerpretation system for recognition of forest vegetation types within the Caspian zone was undertaken as follows:

- Definition of forest types to be recognized.
- Definition of broad Caspian Forest ecozones and interpretation guidelines which shall be considered applicable to particular forest types.
- Definition of photo-derivable variables for descriptive characterization of forest types using 1:25,000 aerial photography.
- Study of utilization of Landsat-1 data for delineation of different forest types.
- Utilization of Caspian Forest inventory data and recent management plan information to locate specific forest stands of known forest type on 1:25,000-scale aerial photography.
- Derivation of descriptive forest type characteristics through stereoscopic photointerpretation of 1:25,000-scale aerial photography.
- Computer analysis of photo-derivable descriptive stand characteristics and corresponding forest types to isolate definitive identifying descriptions.

Soil survey based on Landsat image interpretation

The investigation area is approximately 2,000 km^2 and lies in the northern part of the Alborz Mountains between Sari and Amol. Products employed for this investigation were in the form of 70 mm Landsat-1 images in 4 bands. A soil map (fig. 1) of the area was prepared by a visual approach, using especially an additive color

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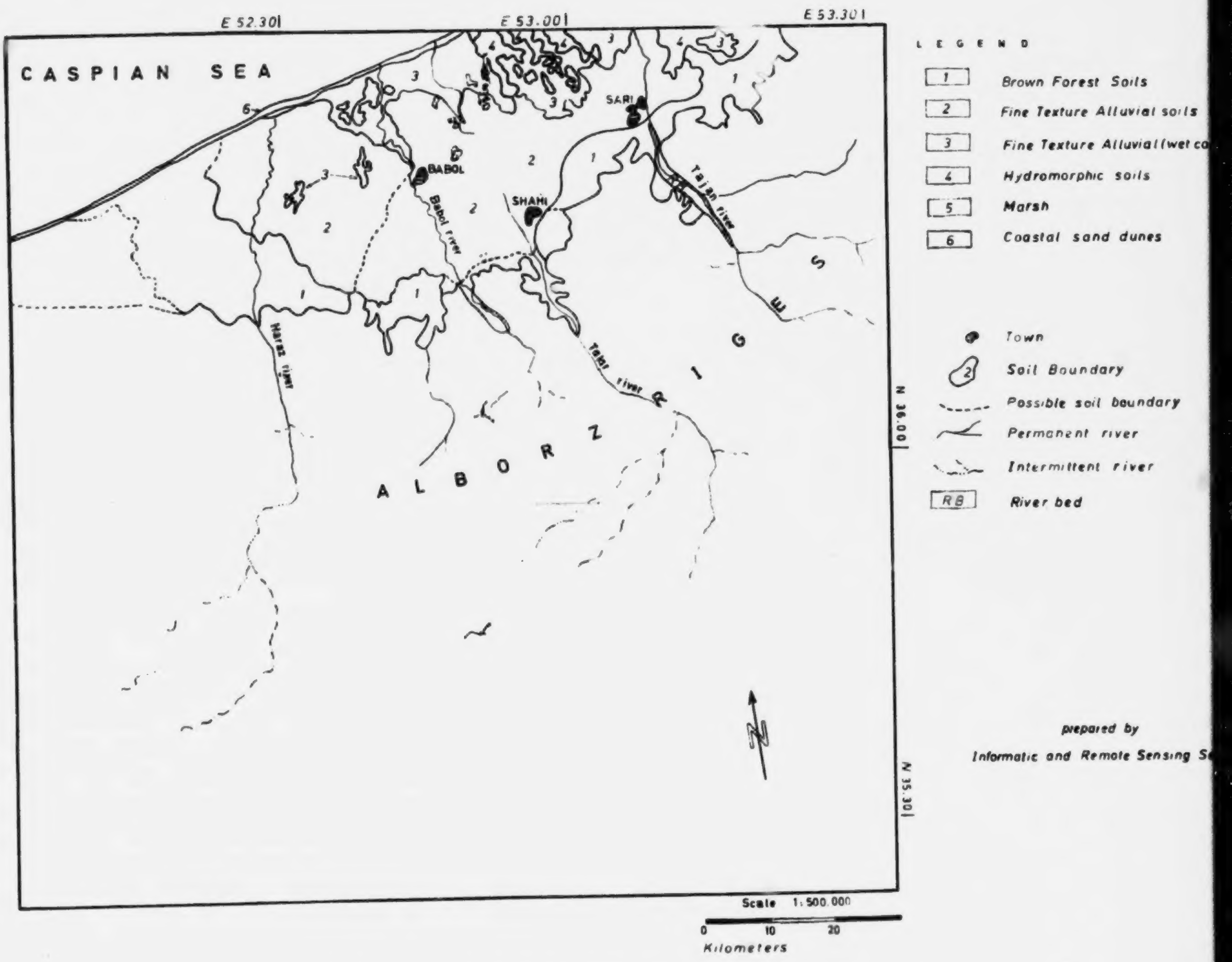

Figure 1. ERTS-1 Interpreted Soil Map of the Sari Test Site

viewer as well as other facilities. Actual basic data were available in the form of a conventional soil map and a topographic map of the Sari region. Six soil types were established on the basis of tone, color, texture, pattern and size of areas recognizable in the imagery, as follows:

1. Brown forest soils
2. Fine-texture alluvial soils
3. Fine-texture alluvial (wet condition) soils
4. Hydromorphic soils
5. Marsh
6. Coastal sand dunes

Figure 1 illustrates the results of this work.

EVALUATION OF REMOTE SENSING FOR FOREST SURVEY

In order to examine the possibilities of using satellite information for classifying woodland, a Landsat scene having center coordinates 35° 55' N. and 51° 19' E. and which includes the Chalus forests, was chosen. For this evaluation, 70 mm transparencies of the MSS bands were used. The device used for interpreting and analysing these transparencies is an additive color viewer which creates a color composite using blue, red, green, and white filters. Such a composite of the 4 bands of the scene was then studied, taking into account the various factors influencing the interpretation of transparencies.

The result of this investigation is a macro division map (1:500,000) in which the forests have been classified into three types (Grades 1, 2, and 3), according to density (fig. 2).

In order to obtain the above results, statistical and visual data derived from the PDP 11/05 computer system were also incorporated. In addition, a 1:250,000-scale topographical map was used after scale conversion was accomplished by means of a reflecting projector.

Encouraging results have so far been obtained from the comparison of this information with data acquired by field survey and other pre-existing information, including statistical data and reports.

At present, transparencies and tapes from the Landsats are being submitted to accurate interpretation and analysis using the following computers: UNIVAC 1110, System 101, and PDP 11/05.

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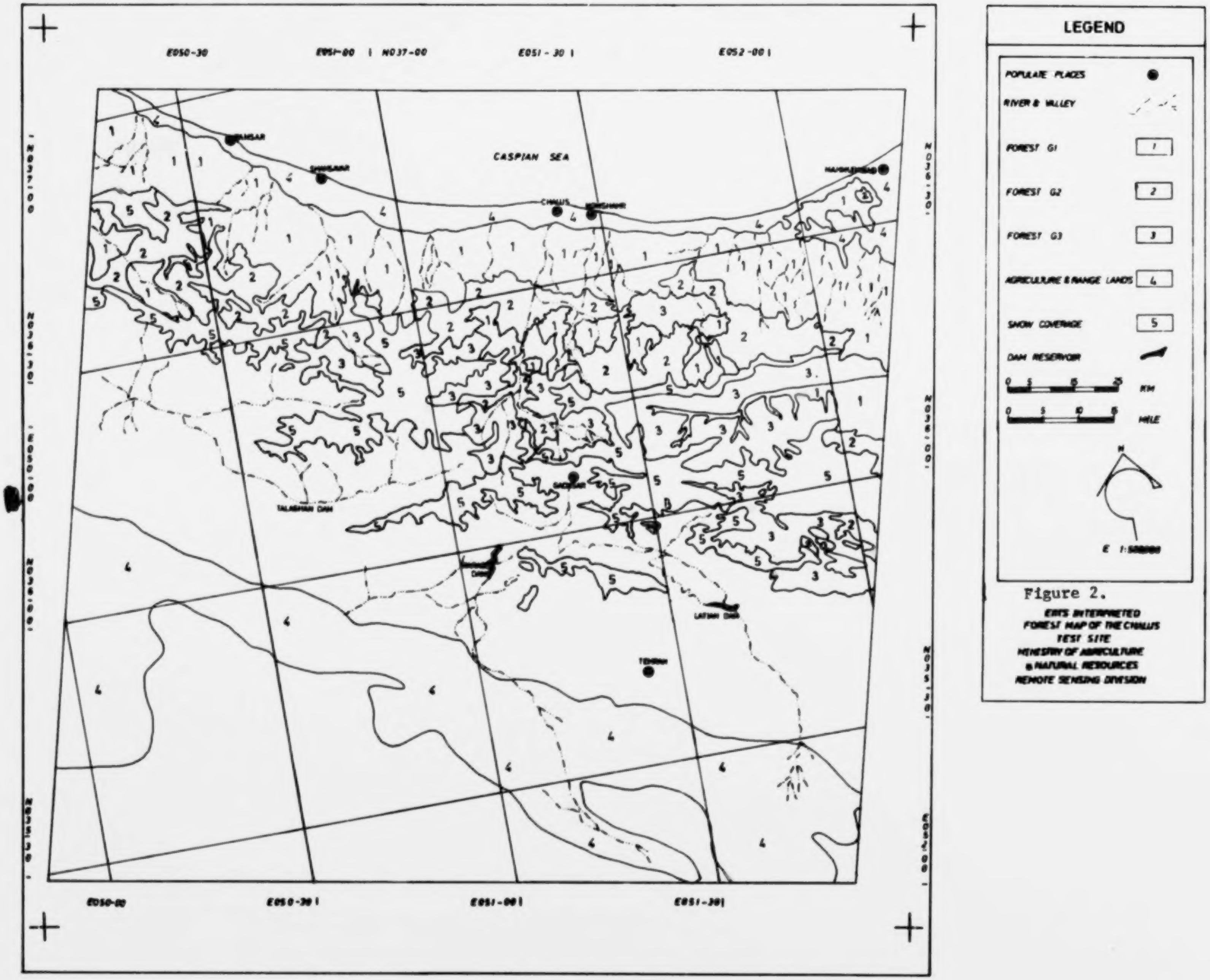

Figure 2.

ERTS INTERPRETED FOREST MAP OF THE CHALUS TEST SITE
MINISTRY OF AGRICULTURE & NATURAL RESOURCES
REMOTE SENSING DIVISION

STATUS REPORT ON THE ACTIVITIES OF
THE SATELLITE APPLICATIONS PROJECT
OF THE PLAN AND BUDGET ORGANIZATION

By Bahman Jazayeri
Plan and Budget Organization Tehran-Iran

INTRODUCTION

An Iranian Remote Sensing Center is currently being organized within the Plan and Budget Organization (P&BO) under the title of the Satellite Applications Project. The project entails the procurement of sophisticated systems for data acquisition; for processing, analysis, and management of earth resources data; and for the establishment of a professional organization and facilities to be used for implementation and operation of the project. This report is an attempt to define the scope of objectives of the project and its present status.

Objectives

The overall objective of the Satellite Applications Project is to utilize earth resources remote sensing technology in programs for development of resources in Iran and neighbouring countries.
Primary objectives are:

To develop a comprehensive earth resources remote sensing capability.

To implement and operate systems for acquisition of earth resources remote sensing data from satellites and from remote sensing instrument platforms.

To implement and operate remote sensing data processing systems to reproduce acquired data in forms suitable for analysis and applications.

To implement and operate systems for storage, retrieval, and dissemination of remote sensing information and data products to other Iranian government users and, ultimately, to regional users.

To develop experimental investigations for application of remote sensing technology to the surveillance and management of Iran's natural resources.

To perform the training necessary to transfer remote sensing technology and applications to other Iranian government organizations and ultimately to regional data users.

Background

In 1972, scientists of the Plan and Budget Organization of Iran were invited by the National Aeronautics and Space Administration (NASA) of the United States of America to participate in the Earth Resources Technology Satellite (ERTS) investigations. ERTS-1 (subsequently renamed Landsat-1) was launched by NASA in July 1972. Data from this satellite were used in a number of applications studies conducted in Iran in the fields of geology, hydrology, oceanography, forestry, and agriculture. Conclusions from these studies confirmed the feasibility of using ERTS (Landsat) data for resource inventory and management in Iran.

Subsequently, in 1974, the Imperial Government of Iran and the United States Government signed a Memorandum of Understanding, under the terms of which Iran was to have NASA cooperation in increased participation in the Landsat program. This increased participation included implementation and operation of a Landsat tracking and receiving facility.

The Landsat-1 observatory is still in operation (October 1976); it is now orbiting concurrently with Landsat-2, which was launched in January 1975. The Landsat program is planned to be extended further by launch of a third observatory in the latter part of 1977. This satellite, presently referred to as Landsat-C, will be known after launch as Landsat-3.

Iran's plans to expand her capability of utilizing Landsat data now include the implementation of a full earth resources remote sensing system (fig. 1). A central facility has been established in Tehran to accommodate (1) project management and administration, (2) training services, (3) a Data Analysis and Utilization Facility, and (4) a Data Management Facility. A remote facility has been located, and land development and building have been initiated to accommodate the tracking and receiving facility and the electronic and photographic data processing systems. A contract for development and delivery of a tracking and receiving facility has been awarded. Tenders for procurement of other major elements of the overall earth resources remote sensing system are presently in preparation or in progress.

REMOTE SENSING SYSTEM OVERVIEW

A "system" is defined as a composite of the organization and equipment required to perform an operational mission. A system includes equipment for checkout, maintenance, and training; facilities in which to operate and maintain the system; personnel possessing the proper skills and trained to operate and maintain the system; and the procedures and computer programs necessary to operate and maintain the system. In addition, the term "system" encompasses all ancillary support equipment. Parts of a system are usually identified as subsystems, components, elements, or, in many cases, systems. All parts of a system must work together to accomplish a common unified purpose.

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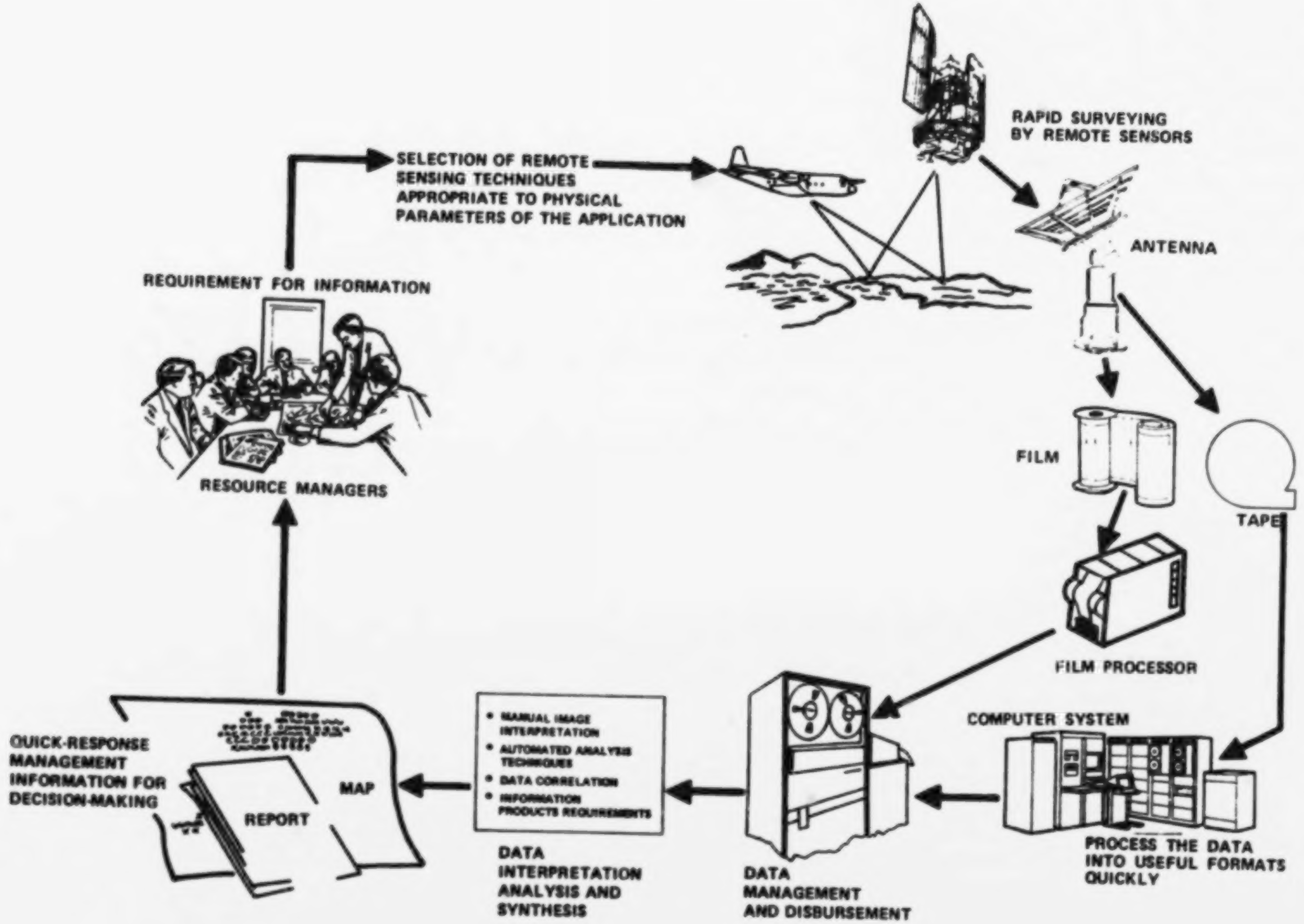

Figure 1. Earth Resources Remote Sensing System.

An earth resources remote sensing system has at least the following capabilities:

To collect or gather necessary data.

To transform or process data into usable form.

To utilize data by analysis, and apply data to original need or requests.

To manage and disburse data, particularly when they are of large volume, repetitive in nature, and specifically requested in various formats.

In contemporary terminology, these basic capabilities are described in terms of subsystems of a total remote sensing system: data acquisition, data processing, data analysis and utilization, and data management.

To support a national program for the acquisition and utilization of remotely sensed data for earth resources applications, the Imperial Government of Iran is in the process of procuring the following major facilities:

Tracking and Receiving Facility.

Electronic Data Processing System.

Photographic Data Processing System.

Data Analysis and Utilization Facility.

Data Management Facility.

These facilities will be integrated operationally into one functional system. Satellite data will be acquired and recorded at the Tracking and Receiving Facility in a format compatible for input to the Electronic Data Processing System. The Electronic Data Processing System will produce imagery on film for processing through the Photographic Data Processing System for output of photographic products, and computer-compatible tapes for use in the Data Analysis and Utilization Facility or in data users' facilities. The Data Management Facility will maintain the data and records of the data and data products stored in the system or processed through the system and will distribute the data according to user requirements.

Data Acquisition System

The Data Acquisition System (DAS) provides for collection of data from various sources as required to support the analysis and applications projects. The system includes the Satellite Tracking and Receiving Facility, ground-truth data-gathering equipment, and ultimately, aircraft remote sensing equipment. The DAS serves as the input to the Iranian Earth Resources Remote Sensing System.

Tracking and Receiving Facility

The Tracking and Receiving Facility (T&RF) serves for tracking orbiting sensor platforms and for receiving and recording sensor data transmitted on telemetry downlinks. The T&RF is a fully integrated facility which includes a Tracking, Receiving, and Recording System (TRRS). Data flow through the TRRS is depicted in figure 2.

Tracking, Receiving, and Recording System.--The Tracking and Receiving Facility has the capability for tracking and acquisition of Landsat earth resources and NOAA meteorological satellites and for receiving, processing, and recording of remote sensor data transmitted from these orbiting platforms.

The Tracking and Receiving System has the capability to receive Landsat MSS and RBV data simultaneously, as well as unified "S" band, telemetry data. Alternatively, it can track the NOAA satellites, and receive Very High Resolution Radiometer (VHRR) data and the NOAA spacecraft telemetry data.

Main features of the system include:

A ten meter diameter antenna reflector.

Dual band capability, 2200-2300 megahertz and 1650 to 1750 megahertz.

Multiple receivers for MSS, RBV, USB, and NOAA VHRR: tunable for alternative utilization.

Serial In, Serial Out (SISO) high-density digital recording of all data, including RBV.

Real time, operator and visitor data viewing displays.

The Tracking and Receiving Facility will be located at a site near Shahdasht-Karaj about 50 km west of Tehran. The site provides a horizon mask which has less than 5° elevation at all azimuth angles. The average mask is about 2-1/2°, which will permit coverage at 5° elevation with high confidence. The regional ground coverage of the TRF is shown in figure 3.

Data Processing System

The Data Processing System (DPS) reproduces the data from high-density digital tapes received from the Tracking and Receiving Facility and produces (1) digital computer-compatible tapes and (2) film imagery in standard forms suitable for analysis. The system includes the Electronic Data Processing System and the Photographic Data Processing System. Figure 4 is a simplified diagram of data flow in the Data Processing System.

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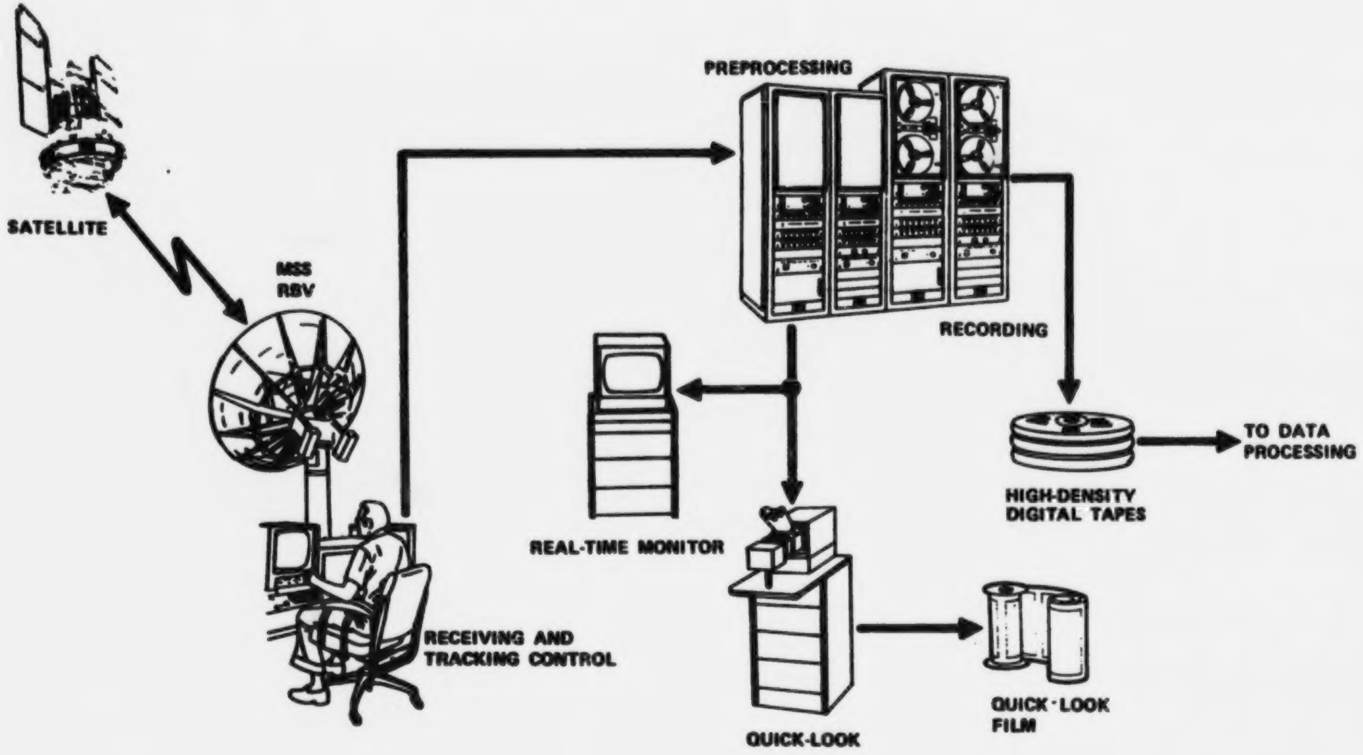

Figure 2. Tracking and Receiving Facility.

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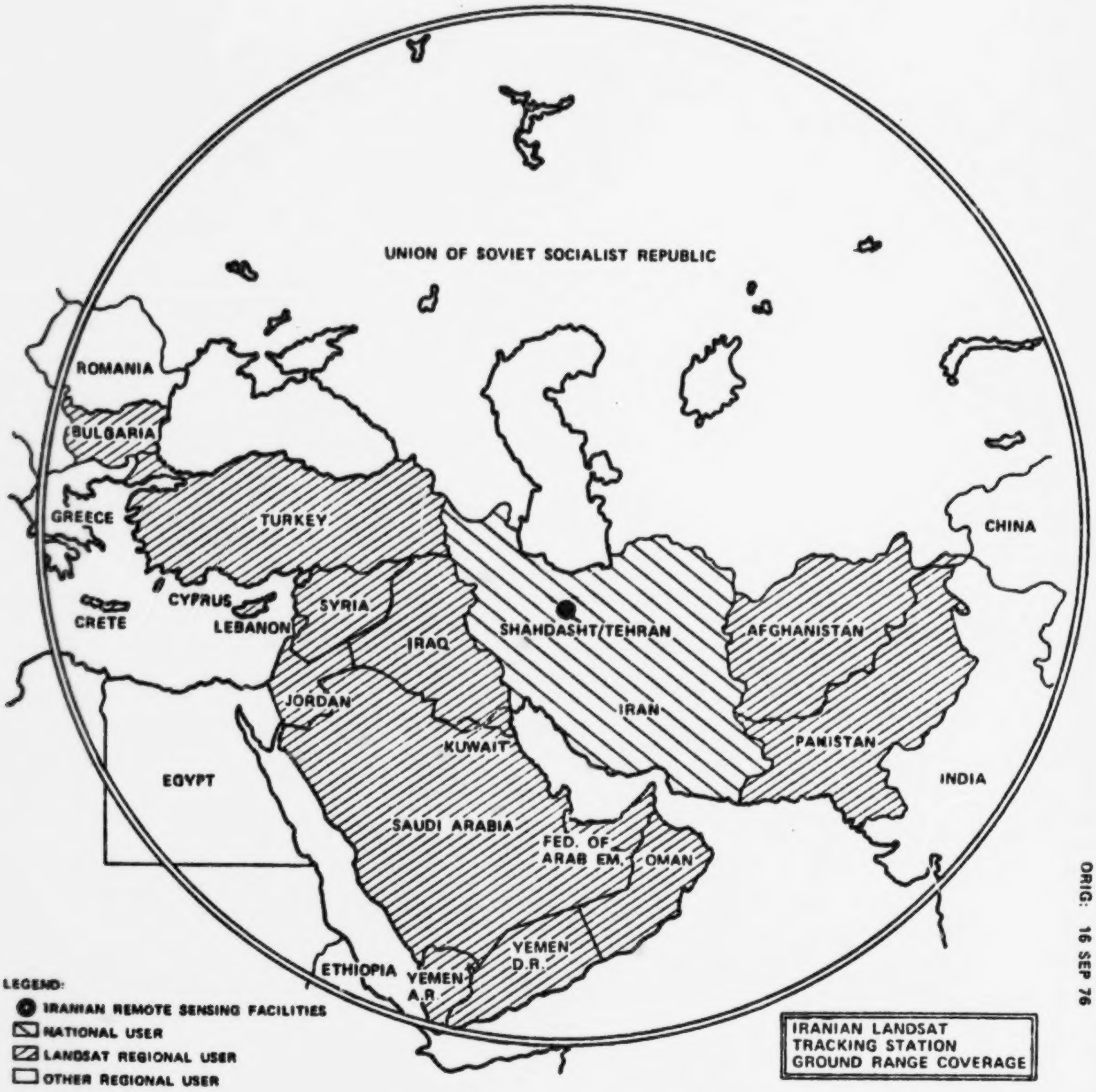

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Figure 3. Iranian Landsat Tracking Station Ground Range Coverage

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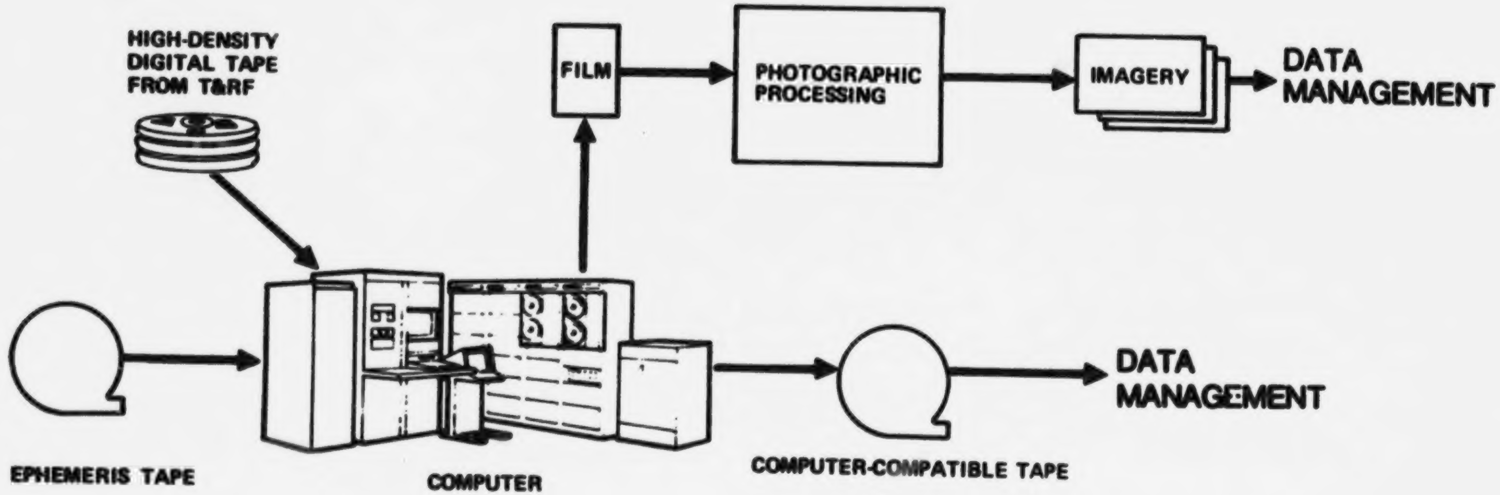

Figure 4. Data Processing System.

Electronic Data Processing System

The Electronic Data Processing System consists of a digital computer with standard input/output devices plus a specially designed high-density digital tape recorder and high resolution film recorder. Data recorded on high-density digital tapes from the Tracking and Receiving Facility are reproduced as input to the Electronic Data Processing System and then processed to produce data output on film and computer-compatible tapes. Ephemeris data furnished by NASA are input to the Electronic Data Processing System from standard digital tapes and are used in conjunction with spacecraft telemetry data to compute image annotation information. During processing of input image data, the computer performs radiometric and geometric corrections.

The input high-density digital tapes may contain Landsat multispectral scanner data, Landsat return beam vidicon data, or data from the NOAA type satellites. These data are reproduced on a serial in/serial out, high-density digital tape unit identical to the recorder utilized in the Tracking and Receiving Facility. The image data from the high-density digital tape unit is input to the system in a format identical to the downlink format received from the satellites. The system reformats the image data for recording on the high resolution film recorder and the computer-compatible tapes. Spacecraft housekeeping (telemetry) data such as spacecraft position, attitude, velocity, and acceleration, in addition to time reference data, are also input to the system from the high-density digital recorder. Data pertaining to the orbit of the spacecraft (ephemeris data) which have been recorded by NASA on standard computer-compatible tapes are input to the system from a standard tape recorder.

The system performs various radiometric and geometric corrections to the data, depending upon which sensor and/or satellite originated the data. In addition, the system also calculates appropriate geometric (latitude, longitude) and time-related information from spacecraft housekeeping data and ephemeris data for use in film annotations.

Photographic Data Processing System

The Photographic Data Processing System will receive exposed original film from the Electronic Data Processing Image Generator (high resolution film recorder), as well as from the Data Analysis and Utilization Facility, ground truth cameras, aircraft data, and the graphic arts area. These original films will be used to generate products in film and paper, black and white or color, in sizes ranging from 16 mm to 760 mm. This system will have the capability to produce multicopies, color composites, color separations, overlays, tone-quality prints for mosaics, and ground-truth motion pictures and slides. Special products include graphic arts, rectified prints, and large display or analysis working prints.

Data Analysis and Utilization Facility

General

Two broad classes of techniques (or methods) for earth resources remote sensing data analysis are widely employed: conventional and automated. The term "conventional" relates to analysis of data in photographic form which had its beginning when aerial photography was the primary source of remotely sensed data. The conventional analysis function is performed by a person (photo-interpreter), assisted by various photointerpretation tools such as stereoscopes, light tables, rectifiers, image enhancement devices, and more recently, computer systems.

The "automated" method is defined as analysis of data with the aid of electronic data processing (EDP). Remotely sensed data, usually input from digital magnetic tapes, are processed with spectral pattern recognition and classification programs, and output for the analyst in card form, paper printouts imagery, or classification (digital) tapes (for subsequent processing in a film recorder).

Perhaps among the conditions most detrimental to the function of an analysis system is the use of conventional techniques to the exclusion of automated techniques, or vice versa, although the borderline between these two techniques is not absolutely clear. An analyst should use all the techniques, procedures, and tools available to obtain maximum utilization of the information contained in the remotely sensed data. The choice of techniques, of course, is dependent upon availability of tools and feasibility of application. Simple photointerpretation tools are not only inexpensive and relatively easy to operate and maintain, but also widely available. Computer systems, on the other hand, are expensive and require specially skilled personnel for operation and maintenance. Applications are categorized as operational (proven) or research.

Data Analysis and Utilization Facility

Currently, within the Plan and Budget Organization, the Data Analysis Subsystem functions as a Data Analysis and Utilization Facility (DAUF). The DAUF is further subdivided into conventional and automated analysis laboratories.

Conventional Data Analysis Laboratory.--In the current project inventory there is an excellent complement of data analysis equipment. There is an optimum mix of standard photointerpretation equipment and photo-optical-enhancement devices to assist the analysts in conventional data analysis. Effective utilization of this laboratory depends upon conformance with standard operating procedures and skill of the analysts.

Automated Data Analysis Laboratory.--The central element of this laboratory is the Digital Image Processing System (DIPS). The DIPS will provide a variety of computer techniques for efficient extraction of useful information from single-band and multispectral data. DIPS will permit the user to control and modify the analysis process, based on his knowledge of the input data and output information requirements. This system will include user-oriented displays and controls, interactive operating modes, and rapid response machine processing.

Data management

The Data Management Facility provides (1) the management and control of data acquired from Landsat observations and of the subsequent data products produced, (2) information essential to the operation, management, and control of the entire earth-resources remote sensing system, and (3) information storage and retrieval services to users.

The utility of a data management system depends on the capability of the system to store and retrieve particular data and information in response to the expressed needs of system users and management. In practice, the data management functions must be interwoven with most elements of a remote sensing system in order to gather information pertaining to (1) all phases of operation, and (2) location and availability of all data products.

Data management is the nucleus of an operational earth-resources remote sensing system. It is the evaluator and control which keep all the functions in balance. An overview of the information and data flow of a typical data management system is shown graphically in figure 5.

Data management system elements

The function of data management system elements ensures the effective management and distribution of data. In theory, these are the most straightforward of the data handling functions, because they are similar to those performed by other common data management systems such as film libraries and computer center archives. However, Landsat experience has shown the data management system to be quite difficult to implement effectively.

The degree of sophistication, and hence automation, required in the data management system depends largely upon the number of product types to be handled, the number of customers to be served, the total system throughput, the management control desired, the user services to be offered, the production and user inquiry response time desired, and the ancillary products (computer listings, catalogues, etc.) to be offered.

Master copies of all Landsat output products generated from the data processing system will be logged, catalogued, and stored in an easily accessible fashion. In addition, information relating to availabilty and location of data, status of production processing and work orders will be readily accessible and retrievable, and made available to users and to management. Work orders to obtain products from the masters will be generated, the work orders and products controlled, and the products quickly disseminated to the users.

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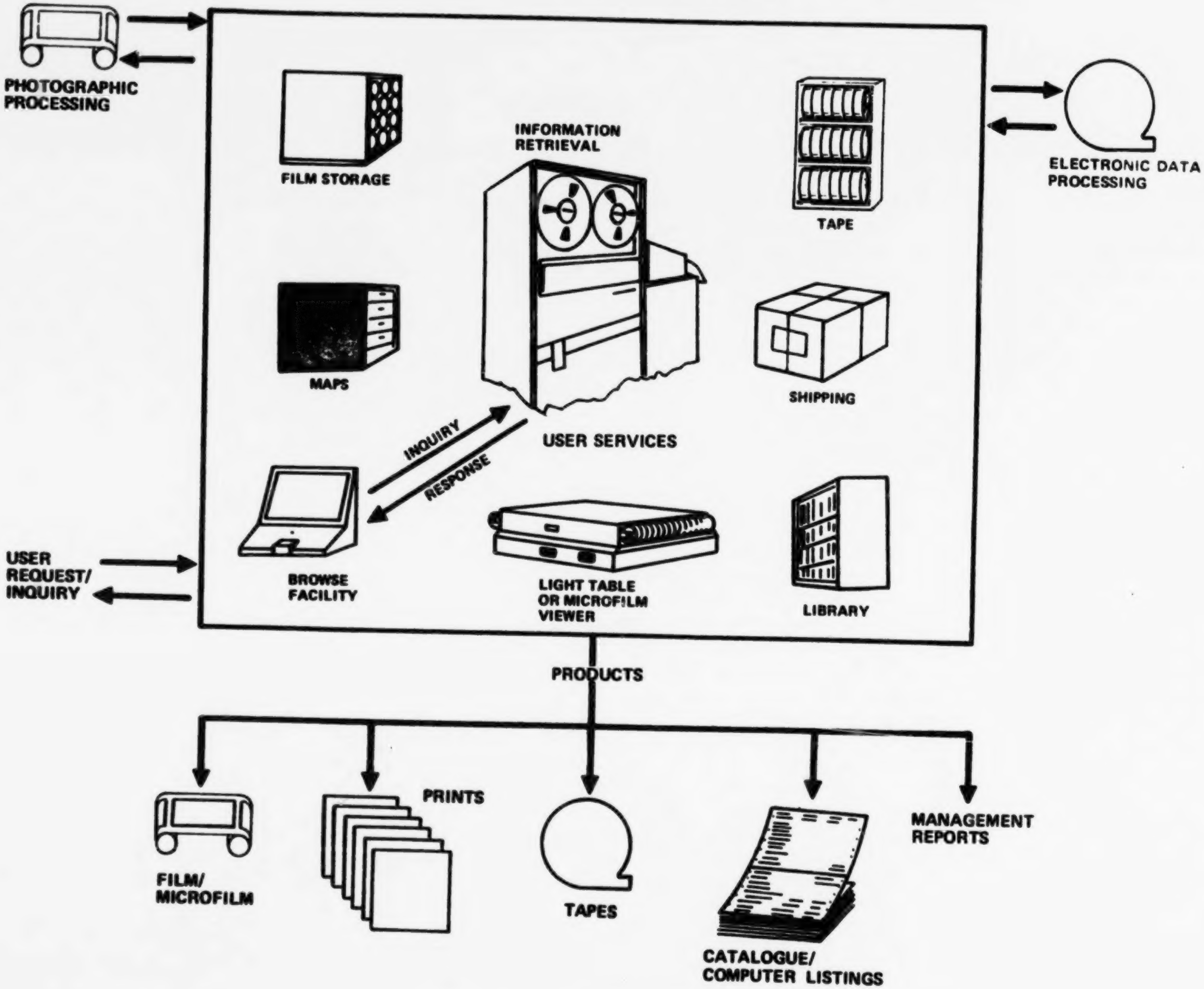

Figure 5. Data Management.

TRAINING

It is recognized that in order to meet the objectives mentioned above, highly qualified personnel will be required. With this requirement in mind, an extensive training program in the full spectrum of the activities from data acquisition to utilization of such data for earth resources analyses and subsequent management, has been initiated by the Satellite Applications Project.

This program is primarily directed toward the training of personnel in Iranian organizations that may require remote sensing techniques for complementing their respective earth-resources programs. It is envisaged that training programs will also cater to non-Iranian scientists, if such assistance is requested

PRE-INVESTMENT SURVEY FOR NATURAL RESOURCES DEVELOPMENT IN NORTHERN PAKISTAN

By Faqir Mohammad Khan
Aerial Forest Inventory Project
Peshawar, Pakistan

SUMMARY

With increase in population, pressure on land for cultivation, grazing, and timber supplies is also increasing in the northwestern hilly part of Pakistan, like everywhere else. But these mountain lands also constitute a major portion of the watershed of Indus River and are thus vitally important as the primary source of the country's water for agriculture, domestic and industrial uses, as well as for power. The quantity, quality, and seasonal distribution of the water flow from these areas is, therefore, of paramount importance to the national economy.

With a view to conserving and developing these watersheds, a project known as the "Pre-investment Survey Project for Natural Resources Development" was launched in 1965 to collect inventory data on topography, vegetation, soils, hydrology, and climate; to interpret these data for the drawing up of land-use plans relative to the needs of sound management of these watersheds; and to prepare management plans for proper working of the forests therein.

The project covers one of the most difficult and inaccessible areas of the world. Altitudes range from about 500 meters to well over 7000 meters above mean sea level. Communication is poor and the area remains covered either with snow or with clouds for most part of the year. Thus, there is a lot of difficulty in flying aerial photography because of the short and not-too-certain spells of appropriate weather conditions as well as the nonavailability of necessary equipment and material. Despite these difficulties, good progress has been achieved on the project in the flying of aerial photography, preparation of maps and drawing up of integrated land resources reports. In some cases, even the follow-up operational projects have been implemented.

The procedure is that aerial photography is carried out on two scales. The small, 1:50,000 scale is used for mapping and the larger, 1:20,000 scale is used for photointerpretation and for photomeasurements. Some of the photo plots are field checked for verification and establishment of correlation, as well as for recording additional information. The data collected through photointerpretation, photomeasurement, and ground measurement are analysed for the preparation of integrated land-use plans.

The results of land-use surveys insofar as these indicate forest areas in some of the watersheds have been checked with the observations recorded from Landsat images. It has been found that the two compare favorably well. With more training, equipment, and material, it is hoped to compare the results already achieved on the project and to apply the use of Landsat images in solving our basic problem of mapping and of carrying out forest inventory in the inaccessible part of the country.

INTRODUCTION

The northern mountain areas of Pakistan constitute a major portion of the catchment area of the Indus River, and are thus vitally important as the primary source of the ocuntry's water for agriculture, domestic, and industrial uses, as well as for power. The quantity, quality, and seasonal distribution of water flow from these areas is, therefore, of paramount importance for the national economy. Consequently, the watersheds need to be rehabilitated wherever necessary and managed properly to minimize soil erosion and siltation, and to maintain optimum water yields.

The country is deficient in forest resource. Out of its total area of 79.6 million hectares, about 6.9 million hectares or 8.7 percent are classified as forestlands. But, the actual area under forests is 2.85 million hectares, that is, 3.6 percent of the total land area; and the productive forests are only about 1.7 million hectares or about 2 percent of the total area of the country. This forest resource currently is, and for the foreseable future will continue to be, the country's primary source of timber for all purposes. At present, the total annual demand for timber in the country is estimated at 1.46 million cubic meters as against the total production of 1.25 million cubic meters. The gap is met through imports. This calls for increasing the productivity of the country's natural forests, which are situated mostly in these northern hilly areas, to help meet the growing demand for timber and other forest products.

These northern hilly areas are heavily populated and there is a great pressure on the land for cultivation by the local people. The cultivation is sometimes practised on steep slopes and extends even above 3,000 meters altitude. Also, the area is being over-grazed by the local cattle as well as the migratory herds.

Thus, the population depends entirely on the use of the local land resources for forest products and food grains, vegetables, fruits, and nuts, as well as livestock and livestock products. The resources husbandry practices are generally primitive and invariably harmful for sustained production at optimum level. Moreover, per capita income is among the lowest in the country and needs to be increased through programs aimed at more effective utilization of the natural resources of the region.

Recognizing the importance of conserving and developing these watersheds, a project known as the "Pre-investment survey project for natural resources development" was started in 1965 to collect inventory data on topography, vegetation, soils, hydrology, and climate, and to interpret these data for the drawing up of land-use plans relative to the needs of sound management of these watersheds. Also, it is intended to collect data of forest areas, forest species, forest quality, and forest measurements, and to analyse these data for the preparation of sound management plans for the working of these forests. Specific objectives of the project are:

1. Obtain aerial photography at 1:50,000 and 1:20,000 nominal scales;
2. Prepare topographic maps on 1:50,000 scale;
3. Prepare land-resources maps;
4. Prepare more accurate volume tables for the coniferous species;
5. Collect inventory data on forests;
6. Conduct feasibility studios for the development of land resources; and,
7. Help draw up operational projects for land resources development in the watersheds.

The project covers an area of about 65,00 km^2 with wooded area estimated at 12,500 km^2. The area falls between 34° and 37° N. latitudes and 71° and 75°15' E. longitudes. A sketch map of the area is given in figure 1.

The area is extremely difficult and inaccessible. It is characteristically rugged and rocky; deep gorges are flanked by very steep ridges which present large variations in altitude, ranging from about 500 meters to well over 7,000 meters above mean sea level. Communication is extremely poor and the area remains covered either with snow or with clouds for most part of the year. Such difficult country, obviously, does not permit easy movements in the field. Thus, ground surveys are too costly and time consuming. Also, there is a lot of difficulty in flying aerial photography because of the short and not-too-certain spells of appropriate weather conditions and because of the limited availability of appropriate material and equipment.

METHODOLOGY OF SURVEY

Aerial photography is flown on two scales--the small 1:50,000-scale photography is used for mapping purposes and the larger 1:20,000-scale photography is used for interpretation and forest mensuration purposes. The photointerpretation details are transferred to maps, and further investigation is carried out through photo plots and then some of these photo plots are field checked for verification, for establishing correlation, and for recording additional information. The data collected from photointerpretation, photo plots, and ground plots as well as from

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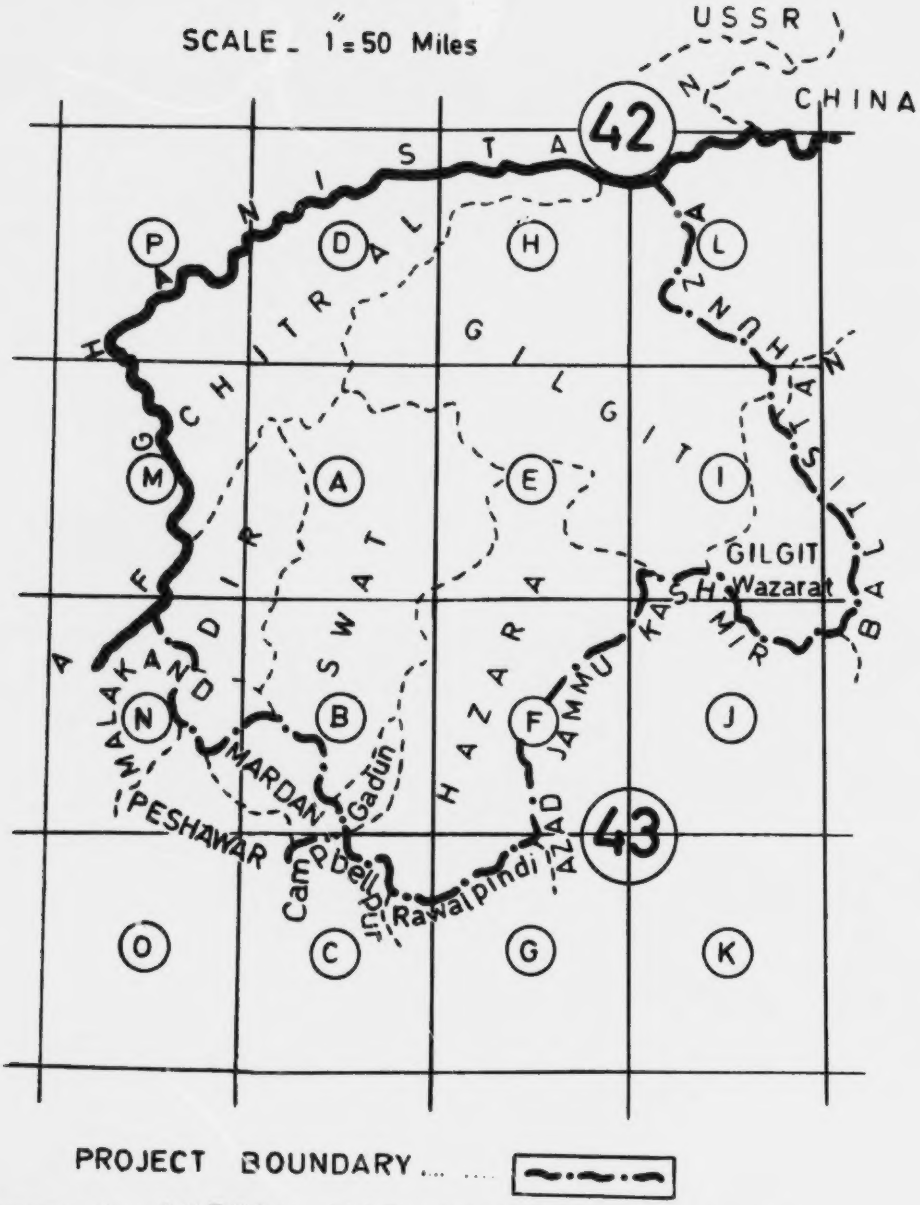

Figure 1. SKETCH MAP OF PROJECT AREA

all other available sources are analysed in the drawing up of integrated land-use plans which are subsequently interpreted into operational projects for the development of land resources in various watersheds.

A manual of instructions (Khan, 1968) has been compiled on the lines of those prepared for forest inventory of Nepal (McCarty, 1964) and survey of forest areas in Greece (Rogers, 1964), and on the basis of experience gained in the field highlighting the local requirements of land-use surveys and forest inventories. These instructions are summarized in the succeeding paragraph, and the various operations are illustrated in figure 2.

Aerial photography.--Aerial photography has been planned at the following specifications:

1.	Material	Panchromatic black-and-white (infrared and colored photography is also available for training purposes).
2.	Lens	Focal length of 6 inches (152.5 mm)[1] for small-scale and 12 inches (305 mm) for large-scale photography.
3.	Datum plane	Mapping: Average elevation of the area under survey.
4.	Scale	Small (minimum 1:50,000) for mapping, and large (minimum 1:20,000) for forestry and land use interpretation.
5.	Tilt	Less than 5 degrees.
6.	Sidelap	30 to 40 percent.
7.	Endlap	60 to 80 percent.
8.	Season	May-June or September-October, depending upon the availability of clear days.

Preparation of maps.--After aerial photography at 1:50,000 scale is carried out, a network of ground control is established and topographic maps are prepared on the same scale. The preparation of topographic maps is a time-consuming process because it involves various operations, that is, establishment of ground control, aerotriangulation, photogrammetric surveying, field verification, fair drawing, and printing. Therefore, pending the preparation of regular topographic maps, drawing up of ad-interim planimetric base maps is resorted to in the early phases.

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[1] The country has adopted metric scales effective from July 1, 1976.

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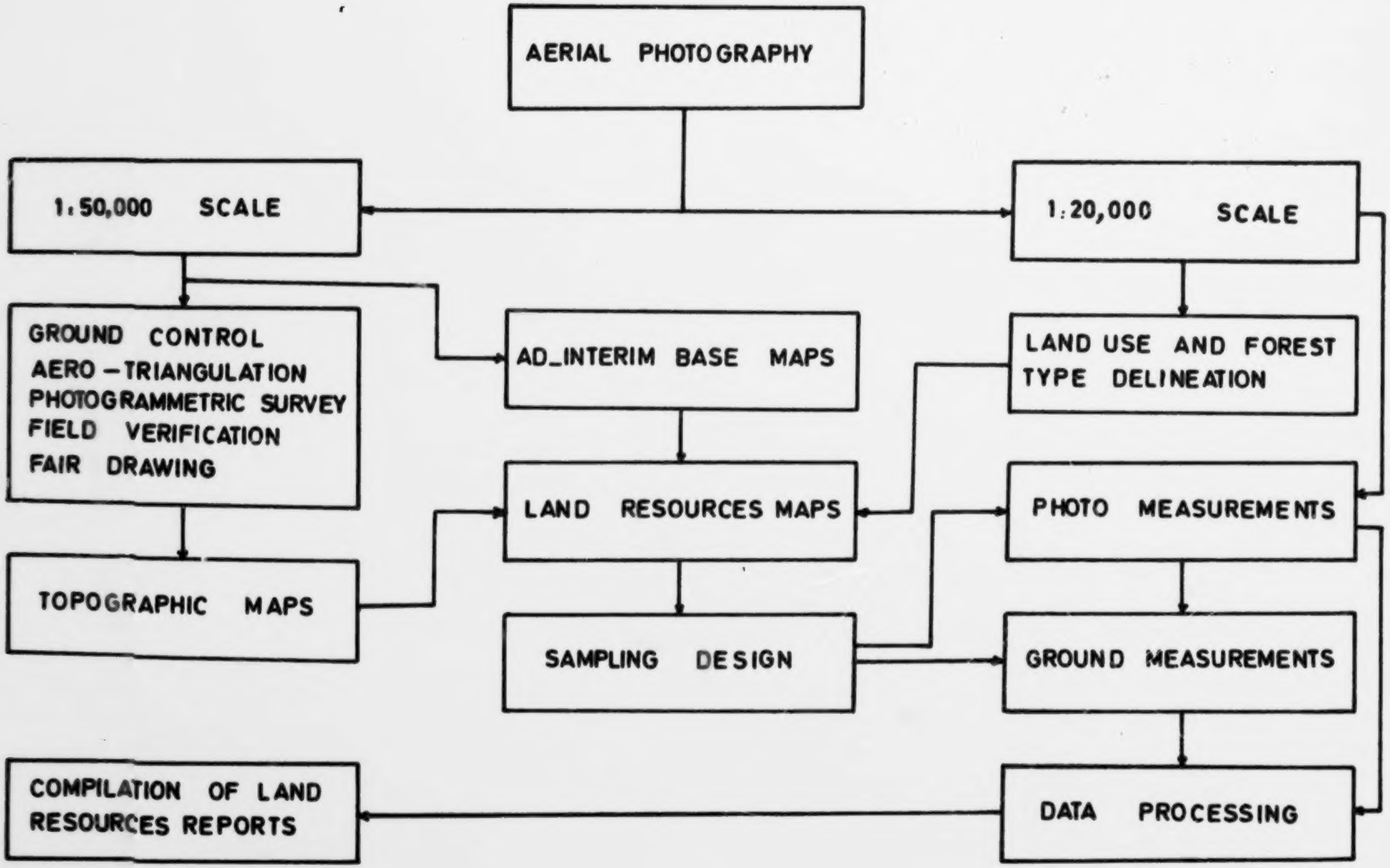

Figure 2. FLOW CHART SHOWING VARIOUS PHASES OF INTEGRATED RESOURCES SURVEY

The area is also flown for photography at 1:20,000 scale. Land-use classes and forest types (cf. Land use and Forest Type Classification) are delineated on this photography and the details are transferred to the base maps in order to prepare forest-type and land-use maps on 1:50,000 scale.

Land-use and Forest-type classification.--A land-use and forest-type classification has been developed. The minimum limit for land-use classification has been fixed at one hectare, and that for forest-type mapping at 5 hectares. The various forest types and land-use classes are as follows:

1. Forests
    a. Coniferous forests.
        i) Chir pine forests.
        ii) Blue pine forests.
        iii) Deodar forests.
        iv) Fir and spruce forests.
        v) Mixed deodar, kail, fir, and spruce forests.
    b. Hardwood forests.
    c. Mixed coniferous and hardwood forests.
2. Rangelands
    a. Submountainous rangelands, below 1,000 m elevation, subdivided into two slope classes: less than 50 percent slope, and more than 50 percent slope.
    b. Mountainous rangelands, between 1,000 m and 3,000 m elevation, subdivided into two slope classes as above.
    c. Alpine pastures, 4,000 m elevation and above.
3. Cultivated lands
    a. Below 1,000 m elevation subdivided into two slope classes, i.e., less than 50 percent slope and more than 50 percent slope.
    b. Between 1,000 m and 2,500 m elevation, subdivided into two slope classes as above.
    c. Above 2,500 m elevation, subdivided into two slope classes as above.
4. Permanently unproductive lands
    a. Roads.
    b. Habitations.
    c. Graveyards.
    d. River beds and lakes.
    e. Glaciers and snow screes.
    f. Rock precipices.

The coniferous forests are further classified into density classes (percent) as 10-40, 40-70, and 70 and above; and into height classes, as 0-10 m, 10-20 m, and 20 m and above. The hardwood and mixed forests are classed in accordance with the height of the main crop in the stand.

Where 1:20,000-scale photography is not available, detailed land-use classification becomes impossible. Therefore, the forests are subdivided into hardwoods and conifers; the latter are further classified into those of north and south exposures.

Area calculation.--As the terrain is very rugged and uneven, displacement in the photography due to relief is bound to be considerable. All areal measurements are, therefore, recorded on the maps either through dot-counting or by using the planimeter. Where, however, maps are not available, the area is calculated by means of dot grids either from individual photographs or from mosaics, if available.

Forest inventory.--Two forms of sampling designs have been developed depending upon the availability of topographic maps and 1:20,000-scale photography. Where these two material types 2/ are available, a double (photo and ground) sampling with regression technique is adopted. A large photo sample is selected and measurements are taken on the photographs. Out of this photo sample, a subsample is taken for measuring and recording of data in the field. The data of sampling units, for which both photo and field measurements are available, provide a basis of adjusting the measurements of the many plots. The photo and field samples are distributed in a systematic manner, because: a) the location of sampling units in the field is easier and cheaper, and b) the distribution of field sampling units is uniform. Also, it has been established that a sample deliberately spread over the entire population will be more representative and efficient than random sampling.

Where large-scale photography is not available, but topographic or planimetric maps on 1:50,000 scale exist, a stratified (ground) sampling is employed.

The sample size for coniferous forest area is worked out through the use of the following formulae (Freese, 1962; Wear and others, 1960):

2/ Double sampling is possible even if topographic maps are not available. This is explained as follows: Datum planes of (a) 5,000 foot and (b) 7,000 foot altitude are specified for the chir forests and high hill forests, respectively. Using a 12-inch focal length lens camera, the 1:20,000-scale photography requires a flying height of 25,000 feet and 27,000 feet above mean sea level for datum planes (a) and (b) respectively. The altitudinal ranges will cause the scale to vary from 1:18,000 to 1:22,000 and 1:17,000 to 1:22,000 for datum planes (a) and (b) respectively. This variation in scale is small and can be ignored. Also, as photo measurements are correlated with those of ground, the regression equation will, to a great extent, account for the said variation in scale.

$$n_g = (\frac{CV}{AE})^2 \cdot t^2$$

and,

$$n_p = n_g\ (R)$$

where:

CV = coefficient of variation of the population;
AE = allowable sampling error in percent;
t = a constant designating reliability of a given level of confidence;
n = number of photo sampling units;
n^p = number of ground sampling units; and
R = optimum sampling unit ratio for particular coefficient and sampling unit cost ratio as read from graph in figure 3.

Further distribution of sampling units to various strata is carried out through proportional allocation for photo sampling and optimum allocation for ground sampling. The formulae are (Freese, 1962):

$$n_{h_g} = \left\{ \frac{N_h \quad S_h}{\sum_{h=1}^{L} Nh \quad Sh} \right\} n_g$$

and,

$$n_{h_p} = (\frac{Nh}{N})\ np$$

where:

n_p = number of photo sampling units to be observed in the population;
n_g = number of ground sampling units to be observed in the population;
n_{h_p} = number of photo sampling units to be observed in stratum h (h=1,...,L);
n_{h_g} = number of ground sampling units to be observed in stratum h
S_h = standard deviation of stratum h;
N_h = total size (number of sampling units possible) in stratum h; and
N = total size (number of sampling units possible) in the population.

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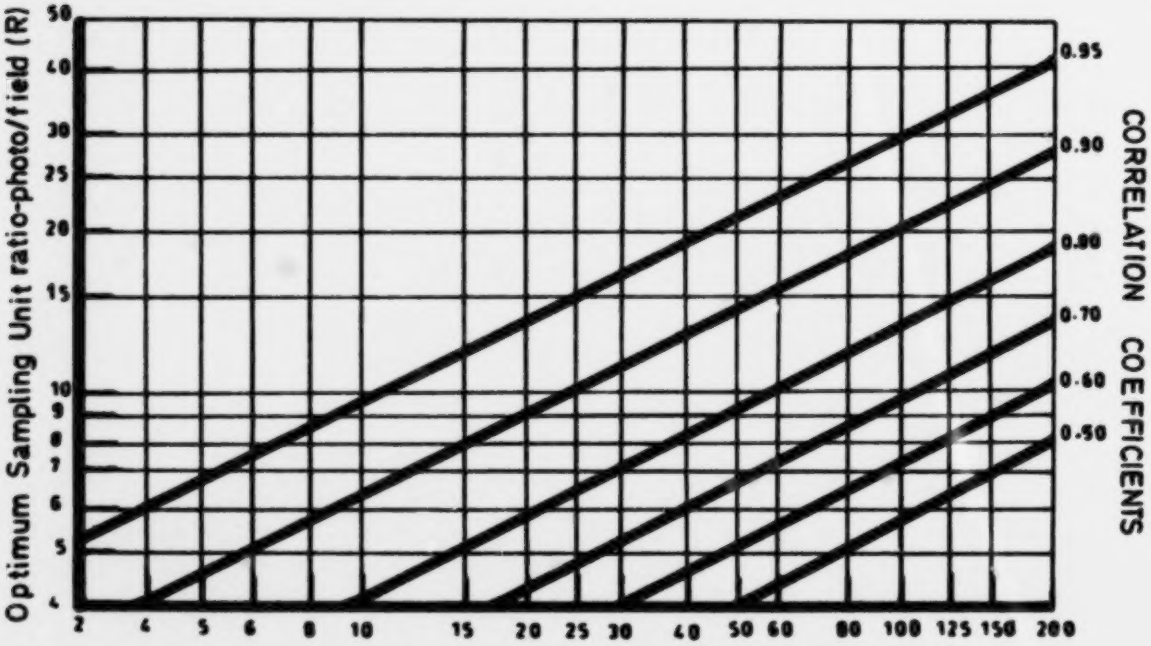

Sampling Unit Cost ratio-field / photo (cf / cp)

Figure 3. OPTIMUM RATIO OF PHOTO SAMPLING UNITS TO FIELD SAMPLING UNITS

For ensuring a better relationship of photo and field measurements, fixed plot sampling is employed in the double (photo and ground) sampling with regression. The sampling units, some of which are examined both on photos and in the field, consist of one acre (now half hectare) circles.[3] A 1/100 acre (now 1/250 hectare) regeneration subplot is taken either at the center of the sample location or at each of the five points in a cluster, whichever is applicable.

The assessment in the stratified (ground) sampling is carried out on the basis of frequency using angle gauge of variable plot sampling. Based on the rule of thumb devised by Beers and Miller (1964), basal area factors (BAF) of 10 and 20 are used depending upon age and density of crop. The sampling units, which are examined only in the field, consist of five variable plots and are distributed in a systematic manner. A 1/100 acre (now 1/250 hectare) regeneration sub-plot is taken at each of the five points in a cluster.

A sketch of the ground sampling unit is given in figure 4. A distance of 200 feet (now 50 m) is kept from plot to plot in the cluster. This is reduced where desirable, but it is never kept less than 50 feet (now 10 m).

Photo data comprise measurements on height of three dominant and codominant trees, crown closure, photo plot volume, and plot description, such as forest type, aspect, slope, soil depth, and erosion. For photo plot volume estimation, either one of the available aerial photo stand--volume tables is used, or else the data collected for the forest inventory is utilised to develop a local aerial photo stand-volume table.

Field data consist of measurements on dbh [4] basal area and volume (worked out later in the laboratory) of each tree: stump height diameter, bark thickness, current annual increment and total height of first (starting from north) three desirable coniferous trees; total height of three dominant or codominant coniferous trees; count of old stumps on the plot; tree description such as species, tree quality and damage class; and plot description such as location, forest type, aspect, slope, density, underlying rock, soil depth, soil drainage, and the suggested treatment for the sample location.

The data are finally processed and compiled in the form of report and forest type maps.

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[3] If it becomes difficult to ensure uniformity among the photo and field sampling units or to measure circle on ground, the photo sampling unit is a circle (for ensuring easy interpretation) but in the field, variable plot sampling is carried out either at one point, the center of the sample location or at a systematically distributed cluster of five points on the sample location.

[4] Dbh in variable plot sampling is used to find the marginal in-trees and volume of all counted trees by using a local volume table.

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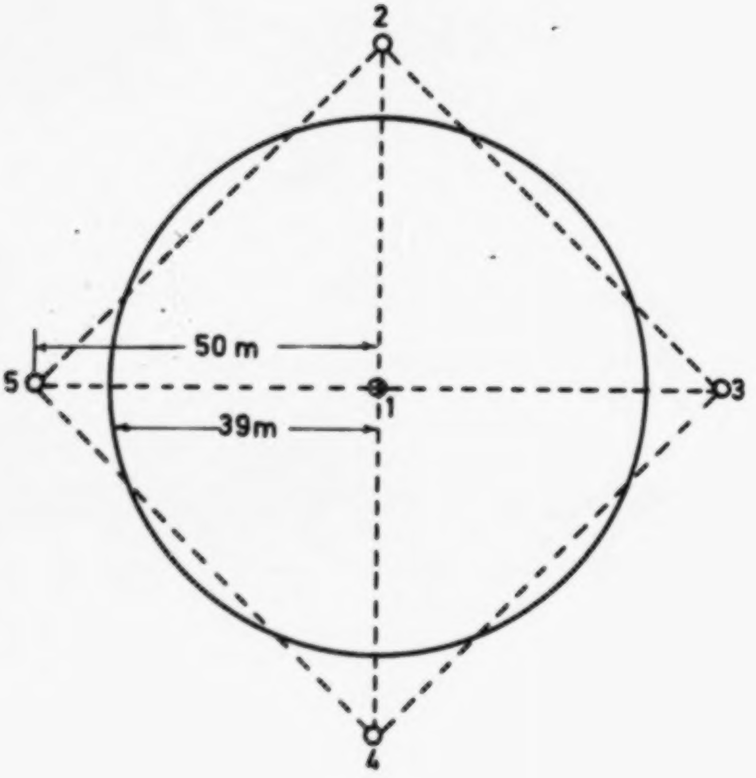

Note:- The ½ hectare circle represents the ground sampling unit in the regression double sampling.

Figure 4. A SKETCH OF THE GROUND SAMPLING UNIT

Land use capability inventory.--The sampling procedure and the size and shape of sampling unit remain the same. The photo sample for coniferous forest areas is enlarged proportionate to the area of different land-use classes to facilitate laying out of the sample systematically on aerial photographs through the use of acetate templates. Every third sampling unit falling on nonconiferous forests area is then taken up for photo measurements. The ground sample is calculated at the rate of one sampling unit per 5,000 acres (now 2,000 hectares).

Photo data consist of information on existing land use, soil depth, soil drainage, slope, and erosion. Ground data comprise information on land-use class, rock formation, soil depth, soil drainage, soil texture, soil color, slope, aspect (if necessary), erosion, and the suggested treatment for the sample location. If the plot falls on hardwood forests, information on the species, frequency, dbh, and the state of regeneration is also collected for the sample location.

Apart from the above, soil investigation is carried out with the courtesy of the Soil Survey of Pakistan over predetermined cross sections to collect data on geology and parent rock formation; soil profile, soil color, soil texture, soil structure, soil drainage, erosion intensity and ph value; and aspect and slope. This information leads to the identification of various soil groups which are distinguished on soil maps.

By nature of the system, corrections for errors detected in the field examination can be applied on a percentage basis to the larger number classified by photointerpretation. Some of the data which could be collected in the field alone are projected as such to the entire area under investigation. The land-use capability, determined from the treatment suggested for a field sampling unit, is projected to all the photo sampling units having adjusted data identical to the ground sampling units.

The information is finally presented in the form of reports, existing land-use maps, and land-use capability maps.

ACHIEVEMENTS

Despite the odds of weather conditions, the difficulty of terrain, and the nonavailability of necessary equipment, material and men, good progress has been achieved on the flying of aerial photography, preparation of topographic maps and land resources maps, collection of forest inventory and land suitability data, and compilation of integrated land resources reports. The detail of progress achieved on the project is approximately given in Table 1.

Table 1. Detail of achievements made to June 30, 1975

Type	Targets (km^2)	Achievements (km^2)	Balance (km^2)
1. Aerial photography:			
1:50,000 scale	50,000	42,000	8,000
1:20,000 scale	40,000	19,000	21,000
2. Preparation of maps:			
Base maps	40,000	39,000	1,000
Topo maps	50,000	35,000	15,000
Resource maps	65,000	27,000	38,000
3. Soil survey	40,000	7,000	33,000
4. Preparation of reports:			
Forestry inventory reports	12,500	6,000	6,500
Land use/integrated resources survey reports	65,000	27,000	38,000

Apart from the progress achieved as shown in Table 1, follow-up operational projects have been prepared which, in some cases, have also been put to implementation. Furthermore, out of the five feasibility studies planned to be carried out, one has already been completed and a second feasibility study has since been started. Similarly, fresh volume tables have been prepared for all the five coniferous species and have already been usefully employed in the management of forests in these watersheds.

APPLICATION OF SATELLITE IMAGERY

Of late, considerable work has been done on the use of satellites in communication, disaster prediction, disaster relief, and land-resources analyses. Heller (1973) has analysed the problems and promises of Landsat imagery in relation to forestry.

Landsat-1 images (36 x 36 inch enlargements, 1:250,000 scale, black and white prints) were acquired from EROS Data Center, Sioux Falls, South Dakota in May 1974, and again in May 1975. In all, there were 16 prints, 12 of MSS band 5, and 4 of band 6. The resolution presented difficulty in delineating forests from the non-forestlands but, with the help of magnifying lens, efforts were made to identify forestlands in two watersheds already surveyed by the project using the conventional aerial photography. The results are given as follows:

Watershed	Forest area as determined from: aerial photography	Landsat images
Swat.	128,000 hectares	177,000 hectares
Kunhar.	48,000 hectares	63,200 hectares

These results seem to be encouraging. It is hoped that with more training, equipment, and material, it would be possible to develop techniques and apply the Landsat images in solving the basic problem of mapping and making inventories of forests in northern Pakistan. For this purpose, the facilities of equipment, material, and expertise available at the Space and Upper Atmosphere Research Committee in Karachi will be made use of.

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AN EVALUATION OF THE UTILITY OF LANDSAT MULTISPECTRAL DATA FOR SOIL SURVEYS AND MAPPING

By A. Mohammadpour
Plan and Budget Organization

ABSTRACT

An area of approximately 2500 square kilometers in Mazandaran Province, northern Iran, was selected as a test site for an evaluation of the utility of Landsat data in identifying soil association. For this purpose, image enhancement techniques as well as conventional image interpretation were utilized. The results of this investigation demonstrate the applicability of Landsat multispectral data for investigations for the following purposes: estimation of soil properties, delineation of the different soil associations, and preparation and updating of soil maps.

INTRODUCTION

The term "remote sensing" has been gathering an ever increasing importance in the field of science and particularly natural science during the last 15 years or so. By this term we mean every method and technique that enables us to gather information about a distant object.

It is clear that satellite imagery, especially that obtained from Landsat-1, has a major impact on earth resources surveys throughout the world. For this reason a soil study, combining the in-house visual interpretation of Landsat data of a selected area near the Caspian Sea in Mazandaran Province, Iran, with complementary field data, was undertaken.

The study subject of this report was mainly concerned with the correlation of Landsat data in the form of imagery with corresponding ground truth and other relevant ancillary data, with the view of obtaining an overall evaluation of various land types in this area.

The main objectives of this investigation may be defined as follows:

1. Overall evaluation of Landsat spectral data for the identification of soil associations, including an assessment of the utility of the additive color-enhancement technique for this purpose.
2. An assessment of the utility of Landsat data for recognition and delineation of various soil groups.

3. An assessment of the application of Landsat data for estimating various soil properties.
4. An assessment of Landsat temporal data for preparation and updating of existing soil maps.
5. An assessment of Landsat spectral images as base maps.

AREA OF STUDY

The area selected for this investigation is located in northern Iran, on the fringes of the Caspian Sea and is part of Mazandaran Province; it occupies approximately 2500 km^2, bounded by latitudes 35° 30' and 36° 30' N. and longitudes 53° and 54° E. (fig. 1).

This area was selected mainly for the following reasons:

1. Agricultural importance of the study area.
2. Availability of a satisfactory ground communication network, facilitating ground truth investigations.
3. Availability of potentially relevant ground truth information.

METHODOLOGY

Landsat images employed during this investigation were in the form of 70-mm and 240-mm black-and-white transparencies and false color composite prints at a scale of 1:1,000,000 made from bands MSS 4, 5, and 7, and black-and-white prints at scales of 1:500,000 and 1:250,000. All the images were taken on January 25, 1973, and May 13, 1973. In addition to satellite data the following information sources were available:

-Conventional Gorgan soil map at a scale of 1:52,000 made in 1963 and later converted to scale 1:200,000.
-Topographic map of the Gorgan region at a scale of 1:250,000.
-Geologic map of the study area at a scale of 1:250,000.
-Some data about the natural environment situation, type, and density of plant coverage and meteorological conditions were available.

The investigations consisted of three different phases as follows:

Phase 1: Visual interpretation of Landsat-1 black-and-white images and false color composites at various scales.
Phase 2: Interpretation of 70-mm Landsat-1 black-and-white transparencies at a scale of 1:3,369,000, using an additive color viewer, drawing the boundaries of various soil types based upon the tone, color, texture, pattern, size, and shape of elements in the images.

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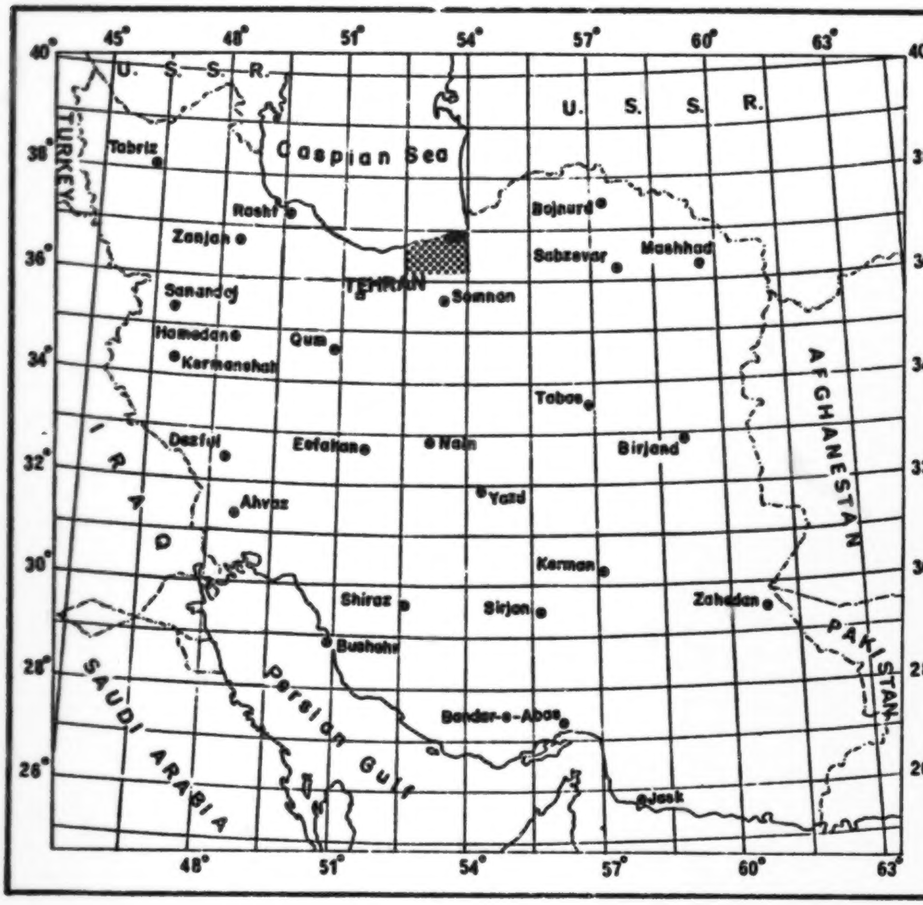

Figure 1. Location of study area in relation to Iran

Phase 3: Consideration of the available ground truth data, and field checking.

In this regard, it should be stated that the methods of conventional aerial photointerpretation as they are applied for soil survey have also been extrapolated for the detailed analysis of Landsat imagery. These methods include drainage pattern recognition, physiographic analysis, and element analysis.

Unfortunately, because of the lack of a digital interpretation system, the digital analysis of the Landsat data was not possible at the time of the present study.

RESULTS AND CONCLUSIONS

Appearance of various landtypes on different MSS bands

A comparison was made between the appearance of different landtypes and certain soil associations in band 5 and band 7 images. The remarks on band 7 are valid also for band 6, because of the similarities of these two; it must be emphasized that this comparison has only local significance and concerns imagery of one particular time.

The facility of drawing an interpretation line meaningful for soil surveys is indicated as mappability. The comparison runs as follows:

Brown forest soil = BF

Appearance:	Band 5	Moderate gray tone
	Band 7	Moderate gray tone with somewhat lighter gray tone
Mappability:	Band 5	Good
	Band 7	Moderate

Remarks: Distinguishing this type of soil from the other units was difficult. For recognition of this group such existing data as location of the area, type and density of plant coverage, amount of rainfall, altitude of the area, and also the soil profile descriptions have been very helpful.

Saline alluvial soil = SA

Appearance:	Band 5	Light gray tone
	Band 7	Similar to band 5
Mappability:	Band 5	Good
	Band 7	Good

Remarks: The light gray tone of this soil group is considered to represent the contamination of the soil surface by salt particles, which would increase the reflectance. The boundary of this area was easily separated from that of the brown forest soils, but separation of this type of soil from salt marsh soils was quite difficult, owing to the similarity of tone. This latter separation has been possible with the use of ground truth data.

Fine-texture alluvial soils = FA

Appearance:	Band 5	Moderate gray tone
	Band 7	Moderate to dark gray tone
Mappability:	Band 5	Moderate
	Band 7	Good

Remarks: The fine texture of the alluvial soils (FA) area imparts a moderate gray tone. However, compared with the saline alluvial soils it has a dark gray tone. This is due to the absence of the salt particles that account for high reflectance form the saline alluvial soil.

Hydromorphic soil = HS

Appearance:	Band 5	Moderate gray tone
	Band 7	Dark gray tone
Mappability:	Band 5	Poor
	Band 7	Good

Remarks: Delineation of this type of soil was performed by utilizing the images of band 7 because, as previously stated, its identification is better in this band than in bands 4 and 5.

Coastal sand dunes = YS and OS

Appearance:	Band 5	Light gray tone
	Band 7	Dark gray tone (without reflectance)
Mappability:	Band 5	Good
	Band 7	Poor

Remarks: Sandy soils and coarse-textured soils have higher reflectance than the fine-textured clay soils. Because of its greater reflectance, this kind of soil always has a lighter gray tone on Landsat imagery than neighboring soil.

Salt marsh soils = SM

Appearance:	Band 5	Moderate gray tone
	Band 7	Moderate gray tone to dark
Mappability:	Band 5	Good
	Band 7	Similar to band 5

Remarks: Generally, the identification of areas of salt marsh soils is accomplished by combining bands 4, 5, and 7 and using various colored filters. It should be remarked that ground truth data have also played an important role in identification of soil type.

River bed = RB

Appearance:	Band 5	Light gray tone
	Band 7	Dark gray tone
Mappability:	Band 5	Good
	Band 7	Good

Remarks: Shape has played an important role in delineating areas of this soil type.

In general, six different types of soil have been recognized in the region (fig. 2). The comparison between the soil map derived from Landsat data and the one prepared through conventional semidetailed study, at an approximate scale of 1:52,173, indicates that, so far as the recognition of the various kinds of soil is concerned, there are many points of similarity between the two (see table 1). However, two areas of residual soils and one of alluvial soil depicted on the conventional map are not plotted on the Landsat-derived soil map because areas are too small to be distinguishable in the Landsat data. Conversely, it is only on the satellite map that an area of 8,000 hectares referred to as saline alluvial soil is observed. There are also some noticeable differences on the two maps with regard to boundaries and limits, and as a result, units appear to be dissimilar; these differences may result from the following factors:

1. The conventional map was made from uncorrected aerial photographs and is only approximate scale.
2. Variations shown in the boundary and limits of the Gorgan Bay are real and reflect water levels at the two observation periods. Its regression since the date of the conventional map results in the extension of some adjacent units of soil in the region.

Table 1

Soil units	Conventional soil map (hectares)	Landsat-interpreted soil map (hectares)
Brown soils and brown forest soils	26040	64800
Hydromorphic soils	53320	46000
Hydrohalogenic soil	41640	28400
Sand dunes	14400	15080
Young alluvial soils	6960	--
Residual soils	2920	--
Saline alluvial soils	--	8320

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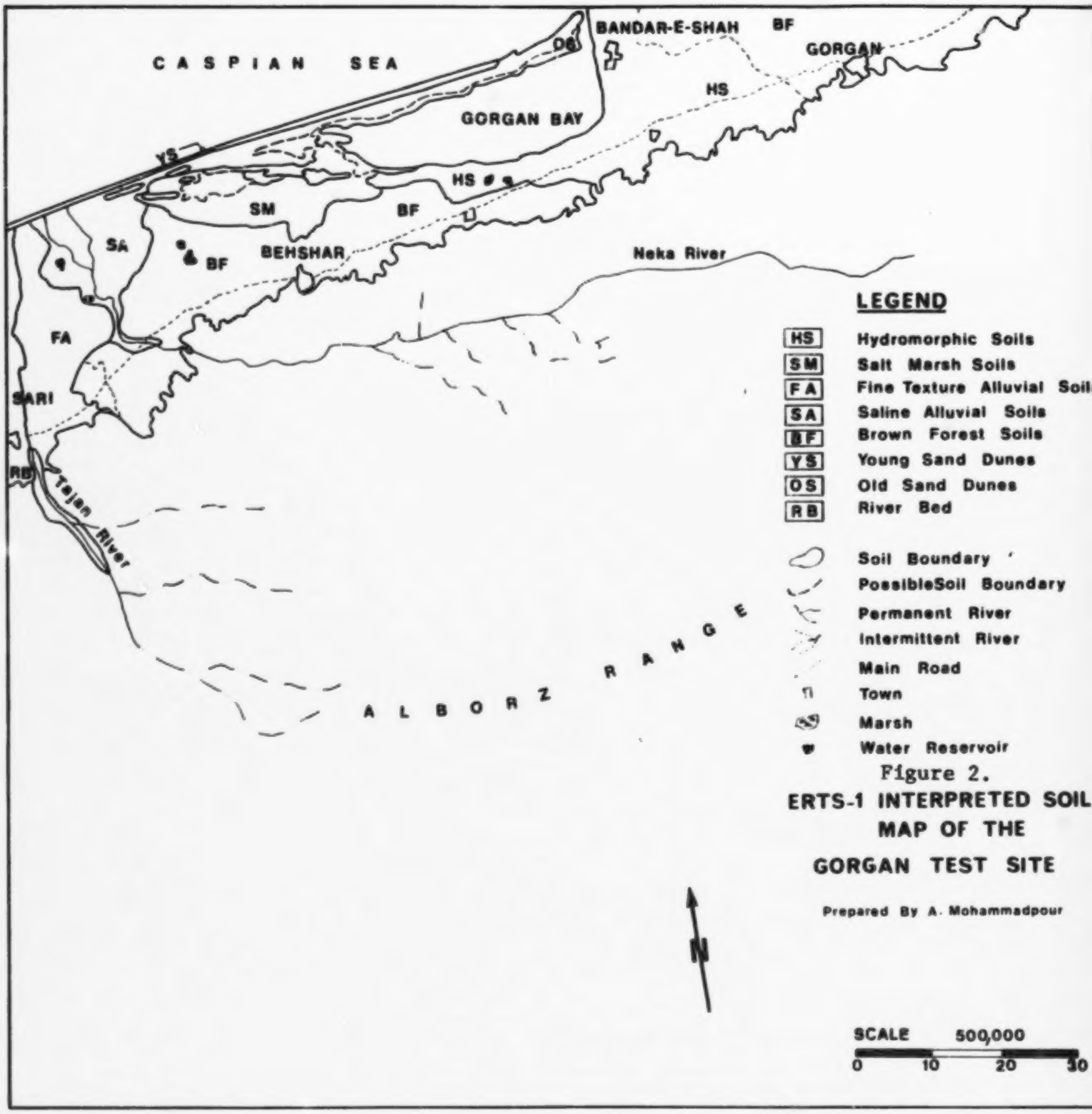

Figure 2.
ERTS-1 INTERPRETED SOIL MAP OF THE GORGAN TEST SITE

Prepared By A. Mohammadpour

As the two maps reveal, Gorgan Bay covered a greater area when the conventional soil map was made in 1963. Now, as shown on the Landsat-derived soil map, the water boundary has decreased on all sides, especially at the Bay's inlet, where it connects with the Caspian Sea, and in the west. A continuous retreat of the Bay over the course of the past 12 years has created large areas of dry land. Today, at the Bay inlet, an area of 3,000 hectares has been converted from Bay bottom to coastal sand, whereas 4,000 hectares at the west of Gorgan Bay that were covered by water now consist of salt marsh soil (SM).

Results of the investigations and evaluations carried out during the course of the present study with regard to both Landsat imagery and other types of data indicate that the Landsat images are easier to use and more accurate tools in soil identification than are the conventional types. They are very helpful for mapping soils at 1:500,000 scale, and yield satisfactory results. In particular, they may be used in revision of the present soil maps and in plotting changes in the boundary and limits of the known soils.

In most cases, in areas without any vegetation or in regions where the total plant coverage is below 20 percent, the gray tones seen on the images represent certain characteristics of the soil because the spectral values observed are the effects of the soil surface reflections. Consequently, the interpretation of the bare soil's spectral reflections is easily accomplished and the result is more dependable. These conditions are taken into consideration in analysis of the gray tones and the classification of the soil types. The effects on gray tones of such factors as high-moisture content or the existence of salt or sand layers covering the earth surface, are also more easily and more accurately interpreted on the basis of an understanding of how the above-mentioned factors affect spectral reflectance.

The satellite images studied so far are not in themselves sufficient for identifying the soils of an area, but together with the use of ground information and local investigations, they provide a precise tool for the study of earth resources.

Use of Landsat imagery offers the following advantages and disadvantages.

Disadvantages:

1. Low resolution and small scale limit the detail available.
2. Stereo vision is generally not attainable.

Advantages:

1. Multiband data aid in interpretation.
2. Repetitive observations aid in interpretation and in the monitoring of changes with season and the passage of longer periods of time.

Satellite information has some unique features of value for the study of earth resources that set it apart form other types such as aerial photography.

Every image covers an area 185 x 185 km, and consequently provides the equivalent of the coverage of 2200 aerial photographs taken at a scale of 1:20,000. This means that it would be necessary to match approximately 2200 aerial photographs to form a mosaic to obtain a general view of the same area of 35,000 km^2 (185 x 185). The resulting mosaic would cover 88 m^2, which is an impractical size for study purposes.

The feasibility of repetitive observation from space is of the utmost importance in the study of earth resources, particularly in such fields as water resources, forestry, and agriculture, which are of a dynamic nature, and in which investigation and monitoring at short intervals must be made.

From an economic point of view, it has been discovered that the cost for employment of aerial photography is 110 times greater than that estimated for employment of Landsat images.

The main reason for using image information is to save time and money. At first glance, the application of hardware for data analysis may seem costly, whereas in reality it will both lower expense and speed up extraction of information to be used in economic planning, and the design of accurate systems for management. For instance, depending upon the method of study used, a classical method like aerial photography, when employed for a general survey of an area may cost approximately 200 to 600 Rials for each square kilometer while the usage of images reduces this amount to a sum of 40 Rials per square kilometer.

Speed and accuracy of analysis by an interpreter employing aerial photography are not comparable with the speed and accuracy attainable by employment of data contained in images, when hardware and other facilities are available.

The efficiency is such that the time required for soil mapping through the use of satellite information is much less than the time required for conventional methods. The only problem is a lack of the necessary experienced personnel and specialists.

A SURVEY OF AGRICULTURE, GROUND, AND GROUNDWATER RELATIONS OF SOUTHEAST ANATOLIA, TURKEY THROUGH LANDSAT IMAGES

By Prof. Dr. Nuri Munsuz
Faculty of Agriculture, Ankara University
and Yalcin Aydos
Ministry of Village Affairs and Cooperatives, Turkey

INTRODUCTION

The Urfa-Mardin-Diyarbakir triangle in southeast Anatolia was selected as the survey area. This area, between long. 39°30' - 41°00' E. and lat. 36°30' - 38°00' N., and the central coordinates of which are about 40°00' E., and 37°30' N., covers an area of 185 x 185 km. The studies were based on 1:1,000,000-scale images in bands 4, 5, 6, and 7, taken on July 15, 1975, and on September 7, 1975, by the Landsat-2 satellite, and also upon black-and-white, 1:500,000-scale band 5 and 7 images taken of bands 5 and 7 on April 15;, 1975.

In the interpretation of these pictures and films, a viewer, a geographical and a geological map of Turkey, and a 1:100,000-scale land map were utilized as auxiliary material. The results from field excursions made in this area were also taken into consideration.

Agricultural areas, use of the land, terrain features, groundwater relations, drainage areas, and such factors as form, size, color tones, texture, pattern, and environmental conditions were considered in the interpretation.

INTERPRETATION

Agricultural areas and land use

The study area can be divided into three main groups from the point of agricultural potential: Dry farming, pasture, and irrigated farm areas.

Dry farming areas.—It can be seen that the areas lying north and south of the study area (about two-thirds of the whole area) are being used for dry farming. These areas where farming is dominant are divided into rather small and irregular plots. Rotation of fallow ground, winter crops, and summer crops can be observed in some of the plots. As there are not enough pictures and bands at hand taken at various times, it is hard to reach a final conclusion about the fallow fields and sown plots and the planting pattern overall. In spite of this, if the Ceylânpinar Duc, (state farm), that is comprised of about 50,000-100,000 m^2 lying in the south of the study area, is examined on band 5 taken on April 16, 1975, it can be seen that the area is covered with growth (probably wheat). The same area is seen to be completely reaped on the July 15, 1975, picture of the same band. It is also deduced that the small plot above the one mentioned was probably left fallow throughout the year. It cannot be viewed in the April picture, but it is quite obvious in the July and September ones. When examined attentively, such conditions may be observed in smaller plots. Plots of a few hundred thousand square meters between the Circip streams were tilled in September and give a dark color. But a final separation could not be made because we did not have a density slicer.

Pasture areas.--It was deduced that the high areas in the center and lying east and west of the study area, and also the high ground in the southwest, may contain sparse pasture ground.

Irrigated farming areas.--This kind of farming can be observed only in the Ceylânpinar Duc area and on some small plots along the Dicle (Tigris) River. The irrigated areas in Syria can be clearly observed.

Also, small plots irrigated by the Devegeçidi Dam and along the north of Diyarbakir can be observed.

Non-agricultural areas

The rocky, undulating, basaltic area around Karacadağ is without growth. Probably there is a weak grazing area at the bottom.

East of Karacadağ, the bowl-like area of 506 km diameter has a light ground cover and is a typical example of a basaltic formation.

Settlements and cultural features

Upon examination of the pictures taken from the bands at various times, though settlements and roads could not be seen uniformly, roads were plotted on the basis of segments that were visible and settlements were plotted on the evidence of the presence of road intersections.

As the area surface is very undulating, small and irregular plots, settlements, and other cultural features cannot be seen at the small scale of the Landsat imagery.

The Devegeçidi Dam and the reservoir behind it may be clearly seen. Also, the variation of water levels according to the seasons is clearly observed.

The Turkish-Syrian border is very obvious on all bands taken at different times. This is because a 300- to 500-meter strip of land is always left vacant.

Soil and topographic conditions

Upon examination, the study area was found to be divisible into four general physiograpic terrain units: high relief, mountainous, high terraces, and low terraces.

Band 5, 6, and 7 images taken at different dates were examined and the boundaries of these four main physiographic units that can be seen by the naked eye were marked on the 1:500,000 Landsat images. These boundaries were drawn according to surface shapes, color tones, texture of the surface, change in the soil moisture, plant cover etc., and it was impossible to characterize small patches of land. Because of this, boundaries were compared to those on the 1:100,000-scale ground map on which they are given in more detail, and small patches shown on the detailed map were amassed into larger areas and shown schematically.

In the study area, basaltic soils on basalt rocks, brown soils on limestone material, reddish-brown soils on hard limestones, brown forest soils on limestone, under-forest-cover non-calcic brown soils, and young alluvial formation in small amounts along the Dicle River were observed.

It is impossible to separate these large groups in greater detail. Yet, some groups were gathered into two subunits. One is smooth, at low slopes of medium depth, and with little erosion. The second is moderately to steeply sloping, shallow or very shallow, and has large erosion areas. Rockiness is characteristic of basaltic areas.

Ground-water relations

Since the area is high and undulating in general, and without closed basins and internal drainage, large differences in tones related to ground dampness were not observed in the various band images. For more detailed information, images taken at different seasons should be compared.

Drainage pattern

Rivers in the north of the high ground at the center of the survey area flow into the Firat (Euphrates), and those on the south side flow into the Dicle (Tigris) Rivers, thus producing two drainage areas.

The drainage pattern of these areas is dendritic. In higher ground the design density is thin. The drainage pattern around Karacadağ runs from the center to the circumference and is a radial system.

ACTIVITIES OF THE GEOLOGICAL SURVEY OF IRAN IN REMOTE SENSING

By I. Navai
Geological Survey of Iran

INTRODUCTION

The Earth Resources Technology Satellite (Landsat) launched on July 23, 1972, began a new era in synoptic, small-scale photo-reconnaissance. In 1971, the U.S. National Aeronautics and Space Administration (NASA) accepted a proposal that Iran participate in this project. Iran was represented by its Plan and Budget Organization which consulted the Ministry of Agriculture and Natural Resources, the Ministry of Power, the National Geographic Organization, the Geological Survey of Iran, and an American consulting company to develop a National Iranian Landsat-1 experimental project.

The Geological Survey of Iran (G.S.I.) has, in addition, participated in a number of seminars concerning the applications of remote sensing:

Central Treaty Organization (CENTO) Seminar on the Application of Remote Sensors in the Determination of Natural Resources, Ankara, Turkey, November 10-13, 1971.

CENTO Workshop on Multidisciplinary Application of Remote Sensing in the Determination of Natural Resources, Tehran, Iran, September 1972.

Interpretation and Usage of Landsat Imagery (ESCAP), Bangkok, Thailand, October 1974.

CENTO Workshop on Multidisciplinary Application of Remote Sensing Data and Methods, Lahore, Pakistan, March 2-8, 1976.

In 1974, a G.S.I. geologist participated in the International Training Course on Application of Remote Sensing at the EROS Data Center in the U.S.A.

In May 1976, G.S.I. arranged a training course on Application of Remote Sensing in Geology and invited an expert from the U.S. Geological Survey (USGS) to teach this course. Twenty Iranians from various departments and three members of the Minerals Research and Exploration Institute of Turkey (M.T.A.) participated in this class.

In July 1976, G.S.I. sent a geologist to participate in a United Nations Food and Agriculture Organization training seminar on the Application of Remote Sensing for Natural Resources Survey, Planning and Development, held at Reading, England.

G.S.I. has participated in a cooperative CENTO/NASA experiment, the Application of Landsat imagery in Regional Investigations of Recent Tectonic and Igneous Geology in Iran, Pakistan, and Turkey.

G.S.I. has received the Landsat imagery of Iran listed below:

1. Two series of coverage by Landsat 1 in black-and-white, paper print, at the scale of 1:500,000.
2. One set of coverage by Landsat 1 in black-and-white, paper print, at the scale of 1:500,000.
3. Partial coverage of Iran by Landsat-2 in black-and-white, 70- and 240-mm positive and negative film and paper print at a scale of 1:1,000,000.

G.S.I. also has two I^2S Additive Color Viewers and one Diazo printer and developer.

FUTURE ACTIVITY IN THE G.S.I.

The G.S.I. and the USGS have developed a joint project to perform computer-image processing of Landsat data covering some of the volcanic terranes of Iran. For a first project, G.S.I. has chosen the area of volcanics in Surk (Central Iran) to be processed and analyzed. G.S.I. will develop a capability to print Landsat images at the scale of 1:250,000, using 70-mm negative film masters in its photographic laboratory. These paper prints will be used as bases for the compilation and correction of geological maps and also as bases for the magnetic map of Iran.

The Plan and Budget Organization of Iran and G.S.I. will collaborate in the future in joint projects involving geological study using Landsat images.

"Deutsche Forschunge Gemeinschaft" and G.S.I. have signed an agreement to accomplish a geotraverse in Iran. This geotraverse covers a band 100 km wide extending from the southwest to the northeast part of Iran.

REMOTE SENSING STUDY IN SAR CHESHMEH COPPER MINE AREA

By I. Navai
Geological Survey of Iran

Hydrothermal copper and subordinate lead occurrences are scattered in the Sar Cheshmeh area, being located exclusively inside the Eocene volcanogenic complex which is intruded by numerous plutonic stocks and massifs. The minerals form impregnations and thin veinlets, with chalcopyrite as the dominate copper mineral. The copper occurrences (Sar Cheshmeh, Darrehzar, Bagh Khoshk, Nowchun) that are related to the plutonic rocks are relatively common and more important than others such as the "porphyry copper deposits" in quartz-diorite and granodiorite bodies in which the copper minerals also contain some molybdenum.

The Sar Cheshmeh orebody is a typical disseminated porphyry copper deposit, with a leached zone developed at the surface followed downward by a zone of secondary enrichment.

North of Guin, in the area locally known as Darrehzar, copper minerals are disseminated in the silicified argillitic and limonitic diorite porphyry. Most of these copper minerals are associated with an oxidized zone at the surface and an abundance of iron oxides.

A project was undertaken, in cooperation with the U.S. Geological Survey, to determine whether Landsat data could be used to locate areas of possible copper mineralization in Iran. The Darrehzar area, north of Guin, was chosen for the study.

The hydrothermally altered rocks of this area appear white on Landsat images because of their high reflectance. As iron oxides of almost any color have a much higher reflectance in the red than in the green, the altered areas appear brighter in band 5 Landsat images than in band 4. However, some of these iron oxides are not distinctive in images of bands 5 and 4 alone, and a significantly higher degree of correlation between Landsat data and the occurrence of areas of iron oxides was attained by computer ratioing of the data.

In this ratioing procedure, the reflectance values of pixels in one band are divided by the reflectance values of pixels representing equivalent locations in another band. The new values derived from the ratioing of scene data for 2 or more band passes may then be used to create representative (ratio) images. These images, in turn, may be used to prepare color composites. The ratioing process may succeed in overcoming the problem caused by similarities of reflectances from different objects when viewed in one of the broad color bands alone and thereby produce a color value more specifically representative of a single rock type or condition.

In this project, bands 4 and 5 and bands 5 and 6 were ratioed. The new sets of values derived were then employed to make a black-and-white film positive image for each. These, then, were used to make a color composite of the Sar Cheshmeh area. The image representing the ratio 4/5 was used to add cyan, that for 5/6 was used with yellow, and that for 6/7 was used to add magenta. In this color composite, most of the iron oxide-bearing areas appeared green and could be transferred to our geological map. In the Sar Cheshmeh area most, but not all, of the copper deposits were associated with these green areas.

After transferring the green areas to our geological map, we found that most of the copper deposits which were indicated on the maps were associated with these green areas, but that there were some green areas for which there was no indication of copper on the map. We checked these areas in the field and found that they are in the iron-oxide-bearing formation, but not necessarily in hydrothermally altered areas. They may be red shale, red sandstone, or alteration areas having a lot of iron oxides but with no indication of copper.

As mentioned above, iron oxides can be of any color, but generally they appear with higher reflectance in the red. Areas of iron oxide should then be much brighter than the other formations in band 5 of Landsat images. In the Landsat images of the Sar Cheshmeh area, the Sar Cheshmeh copper mine appears in very light gray to white tones. On comparison of Landsat single band images, especially bands 5 and 7, and ratio color composites, most of the intensively altered areas are seen to be evident; but, as has been mentioned, in the ratio images, some altered areas which are not clear in Landsat single-band images become clear.

In an associated experiment to determine the value of optical enhancements, false color composites of Landsat images were developed using a color additive viewer in a mode in which highly altered areas were made to appear white. The results of this work have indicated areas of Iran in which mineral exploration should be carried out.

MOVEMENT OF COASTAL WATERS ALONG THE BLACK SEA COAST OF NORTHWEST TURKEY:

DATA FROM LANDSAT IMAGES

By T. Norman
Middle East Technical University
Geological Engineering Department, Ankara

ABSTRACT

Landsat multispectral scanner (MSS) images, covering an area along the Black Sea coast of northwest Turkey, between the mouths of Sakarya River on the west and Filyos River on the east, have been studied to establish the prevailing coastal currents. These two rivers, together with a number of smaller streams, provide sufficient silt discharge plumes to provide useful qualitative information about the movement of coastal water masses. It appears that, while dominant surface currents flow eastward and northeastward parallel to the coast, subsurface currents within the top 30 meters of the sea flow simultaneously in the opposite directions, at least some of the time, if not always. This behavior produces a "corkscrew" appearance in the plume shapes of river discharges. Under strong surface winds, plumes are affected accordingly, and under such conditions, do not yield any information on the subsurface currents. In conclusion, it can be said that the synoptic view, multiband images, and repetitive coverage obtained by Landsat provide a rapid semi-quantitive way to study coastal water movements over wide areas of the ocean. Better results would be obtained if ground data could be obtained during the periods before and after the taking of images.

INTRODUCTION

On many aerial photographs and on Landsat-1 and 2 images of coastal areas, silt discharges from streams into lake or sea basins are clearly visible. These discharges appear as light-gray density plumes, which are usually deflected in the basin water by the dominant currents present at the time when the images were obtained. This study was initiated to determine what information can be obtained from Landsat scene images on coastal currents of the northwest Black Sea of Turkey, when correlated with available ground measurements.

An area was chosen along the western part of the Turkish Black Sea Coast, in which two large rivers, Sakarya and Filyos, could be seen discharging silt into the sea (fig. 1). Two smaller streams, each to the east of the main rivers, were also discharging silt, in lesser volumes. This area is covered by a single pass of Landsat-2

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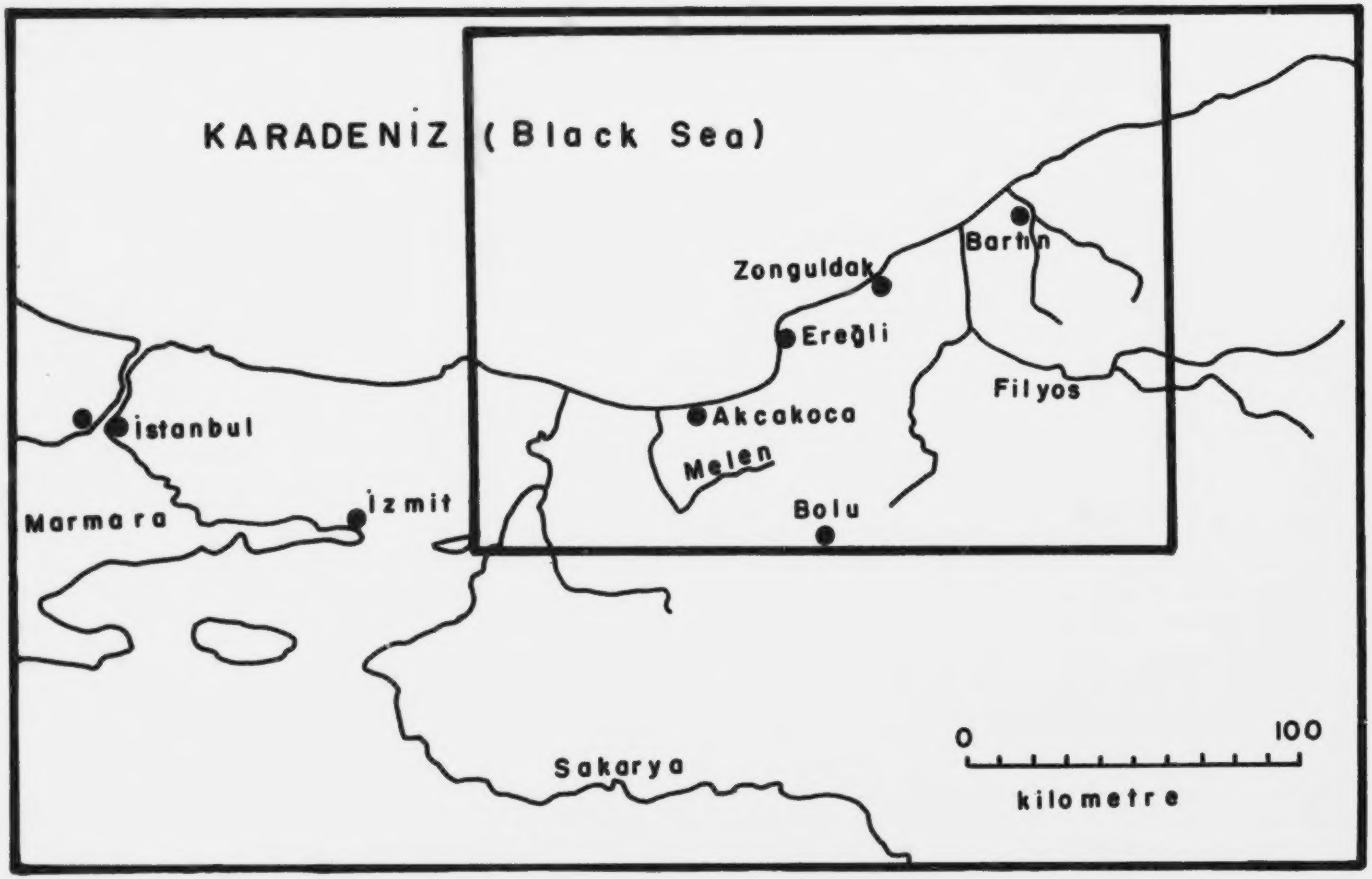

Figure 1. Index map, showing the study area.
Insert shows location in Turkey.

(June 16, 1975, 2145-07565). Coverage of the western half of this scene area is available for the next day (June 17, 1975, 2146-08024), and for an earlier date (May 30, 1975, 2128-08023). Therefore, limited repetitive coverage is also available.

Selected enhanced black-and-white prints of bands 4, 5, 6, and 7, at scales of 1:1,000,000, 1:500,000, and 1:250,000 have been studied, and relevant lines recorded on map-sheets with the aid of a Zoom-transferscope.

SHAPES AND CONTOURS OF PLUMES

On the images of the four bands, low-density silt plumes of river discharge are seen varying in shape and density range (fig. 2). In band 4 (blue-green wavelengths), there is the widest shape, greatest size, and maximum detail of the plumes recorded. In the higher bands, all these features are progressively reduced, to the extent that, in band 7 (infra-red, 0.8-1.1 micrometers) a very small or no plume is observed. This is closely connected with the penetration capability of the light waves in this part of the spectrum. It is well known that while waves at the blue end of the visible spectrum can penetrate water to some depths (typically 10-30 m), longer waves (e.g., green, orange, red) have progressively less power of penetration into water. The infra-red light waves of the seventh band are absorbed at the surface of the water.

Thus, it seems possible to trace the plume limits from each band image, and superimpose them on each other, to obtain a type of qualitative contour map of the plume (figs. 3 and 4). Sub-contours can be drawn to aid the interpretation by estimating iso-density lines. (A density-slicer would do a much more accurate job, but none was available).

By this method, the 3-dimensional shape of the plume, with its subtle details can be obtained. This would not have been possible with ordinary aerial photographs in which the reflected light of all wavelengths would be observed and printed together to form a single image.

With the aerial and depthwise shape of the plumes clearly established, it is now possible to interpret and correlate this information with regard to coastal currents. At any given instant, the shape of the plume is determined mainly by river discharge, coastal currents, and the settling rate of the silt, which is a function of grain size. Since the bottom of the sea slopes very steeply, its effect is assumed to be negligible in this case. The amount of river discharge is one of the factors which determines the size of the plume, while the velocity of discharge influences the initial shape of the plume. Coastal currents modify this shape by bending it in the current direction, and by

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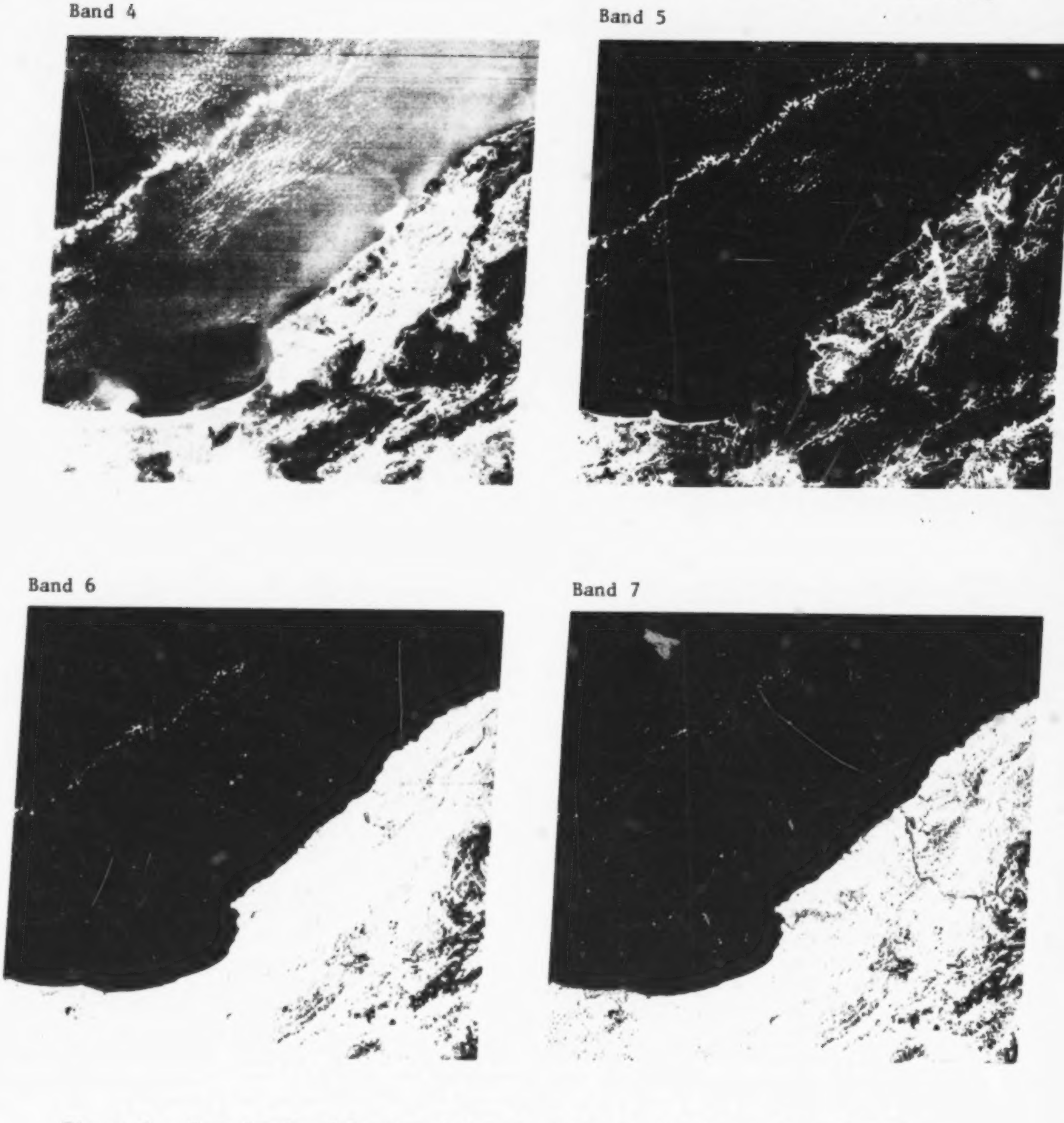

Band 4

Band 5

Band 6

Band 7

Figure 2. Four bands of Landsat-2 image of the study area on June 16,1975. Note the variations in the shapes and tonal densities of plumes between different bands.

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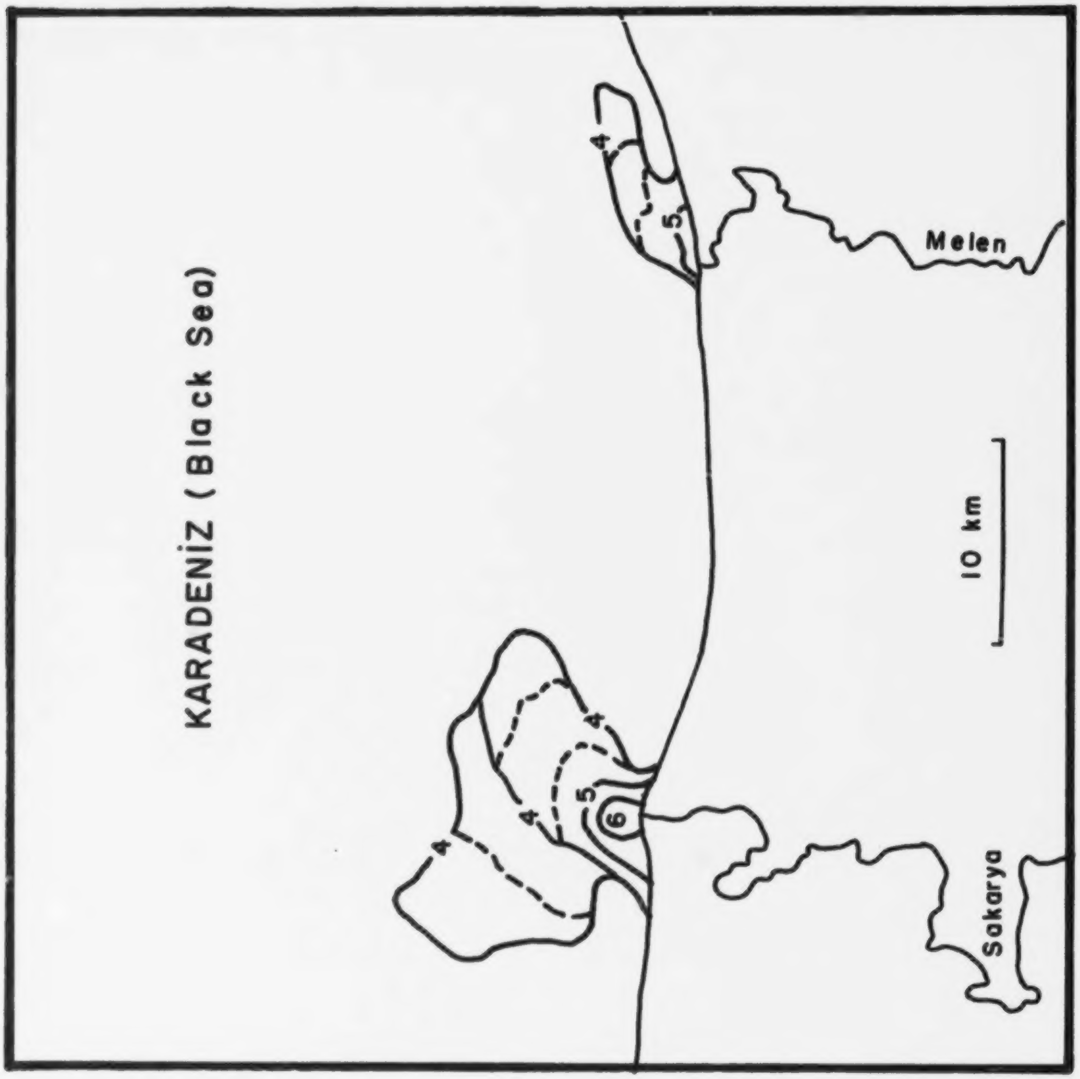

Figure 3. Qualitative contours of the Sakarya and Melen plumes on June 16, 1975. Figures on contours indicate bands. Broken contours are based on estimated iso-density (gray scale) lines within the relevant band.

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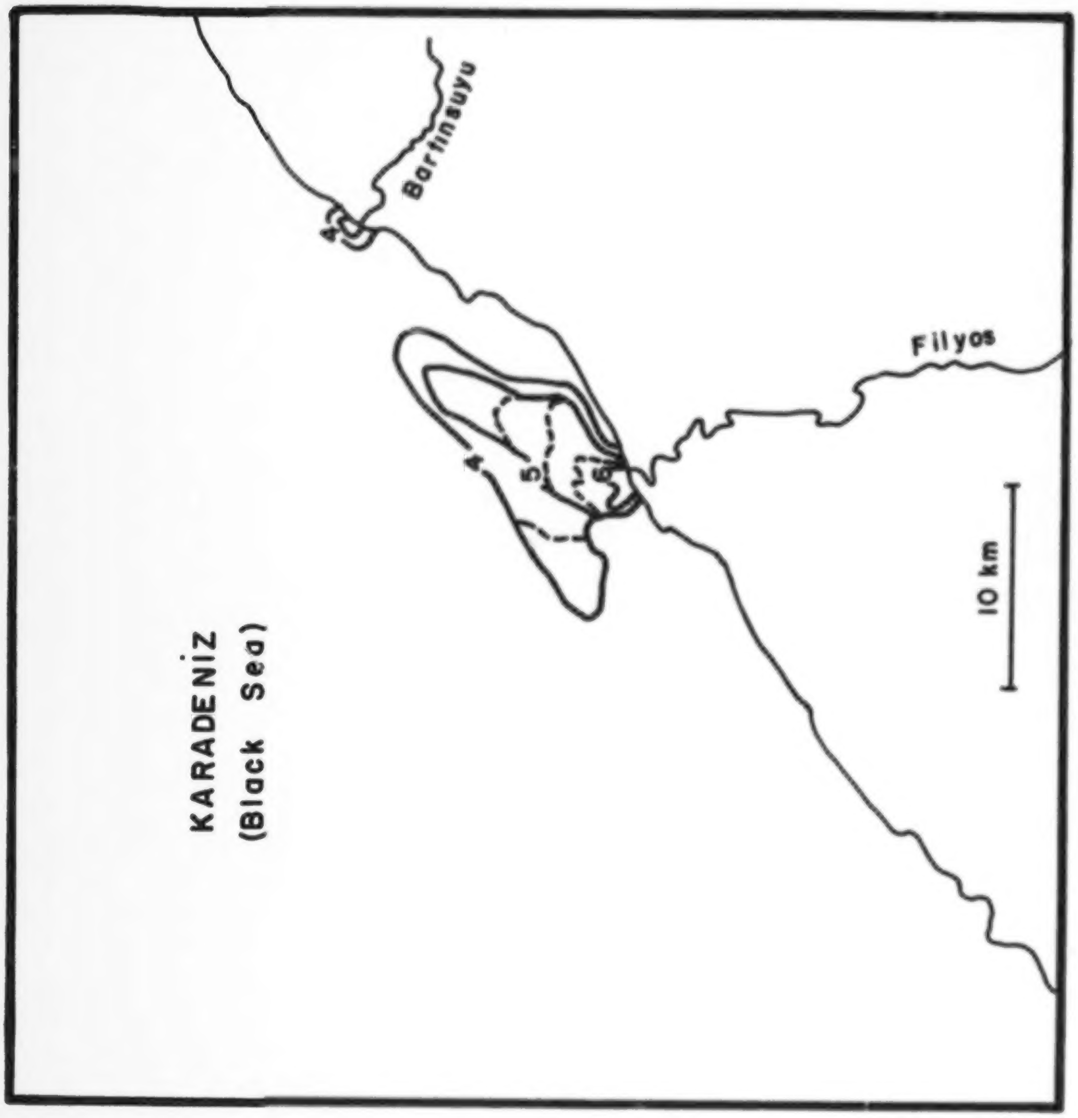

Figure 4. Qualitative contours of the Filyos and Bartınsuyu plumes on June 16, 1975 (for explanation see fig. 3).

spreading the silt over a widening area. The settling of silt grains tends to reduce the area extent of the plume. However, if it is assumed that for a short period there is a constant supply of material, it can be said that the shape of the plume during that short period is not affected by the settling of silt. Then, the main factor which determines the shape of a plume appears to be the local current(s) in the basin. Thus, it becomes clear that a silt plume on the image is a three dimensional body, which can yield information about the direction and velocity of coastal currents.

STUDY OF THE IMAGES

The study of the Sakarya and Filyos plumes in the Landsat-2 image of June 16, 1975, indicates the existence of at least two coastal currents, flowing at different levels in the sea. On the images, these plumes (together with the smaller ones of Melen and Bartınsuyu streams) appear to be bent toward the east and northeast under the influence of surface currents (fig. 5). The contours of deeper parts of the plumes, however, indicate a deflection back toward the west and southwest, (figs. 3, 4, 5) this "corkscrew" shape forming presumably under the influence of currents in deeper layers. This deflection is assumed to take place within the top 30 meters of water, as this is considered to be the maximum penetration depth of the blue-green wavelength.

Large river plumes, probably because of their greater volumes and initial velocities, move away from the coast and show the current reversal with increasing depth quite clearly. Plumes of the smaller streams tend to adhere to the coast and appear to be bent only by the surface currents toward the northeast. The great amount of fine silt discharged, particularly by the Melen stream east of Sakarya, forms a secondary, thinner plume and extends a long way to the northeast (fig. 5), curving along with the shore of the Bay of Ereğli, then, around the headland (and reducing the surface area of the plume to 5 km, owing to the presumably higher current velocity) and extending as far as the mouth of the Filyos. There it attains a width of 40 km, and terminates almost suddenly, perhaps by being caught by the reverse current below. A similar appearance can be described for the plume of the Bartınsuyu, a secondary stream. It should be noted that the finest material of the river plumes (fine silt and clay) would take several days to sink to a depth of 20-30 meters (e.g., for fine silt of 10 mm size, it would take about 1.5 days to reach a depth of 10 meters; clay-size grains will take even much longer). The line where such fine-material plumes disappear may represent the place where they have reached the zone of reverse flowing currents.

Of the other two images, those for the western half of this area, the one of June 17, 1975, shows a change in the Sakarya plume size, with

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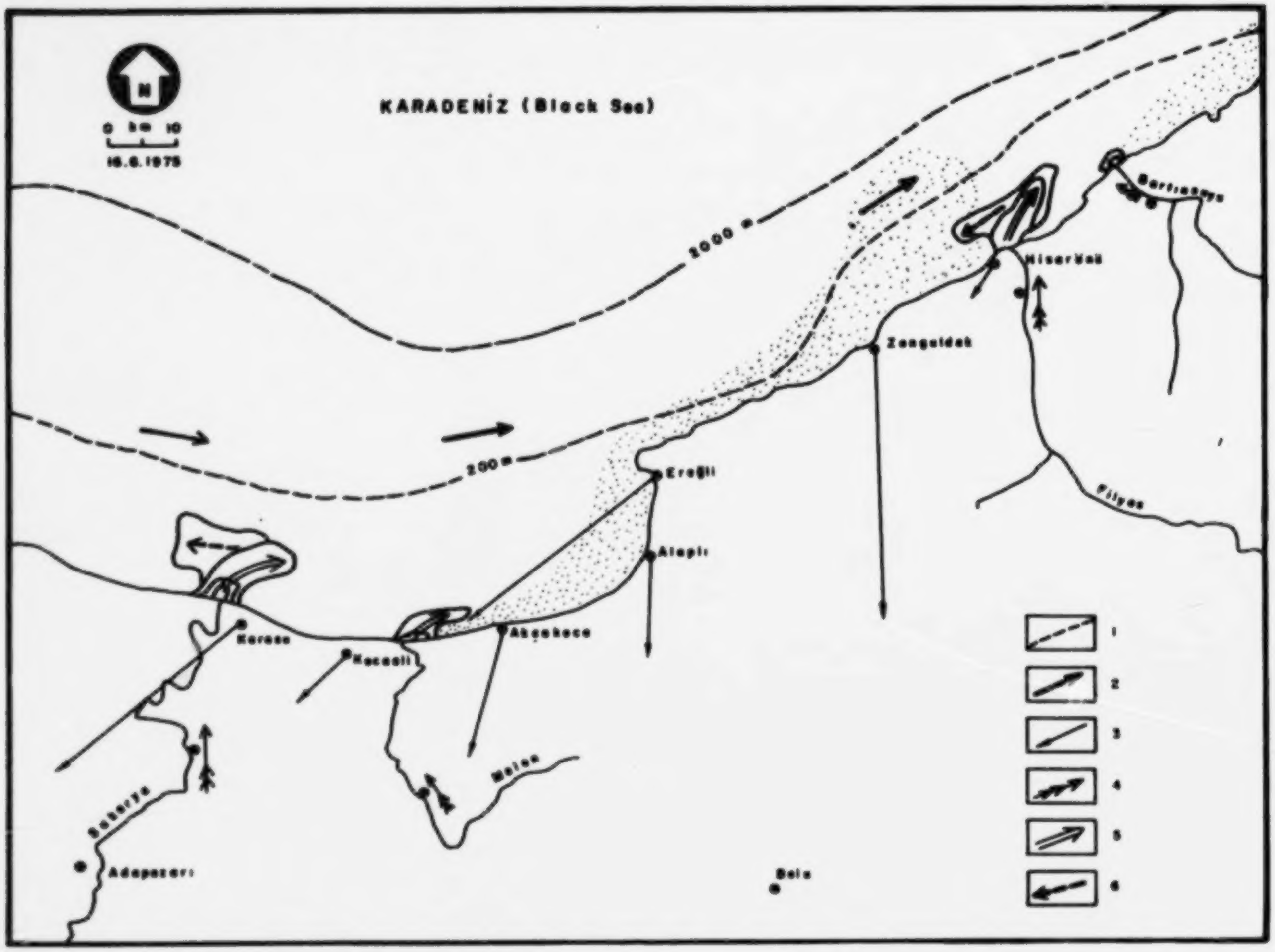

Figure 5. Plume and inferred current directions, together with available ground data, for June 16, 1975.
1. Bathymetric contours (m). 2. Average surface current directions for the month of June. 3. Wind directions measured on June 16, 1975, at about 08.00 GMT; arrow length is proportional to wind velocity (m/s). 4. Stream discharge (m3/s). 5. Upper current. 6. Lower current.

less apparent subsurface current directed toward the west (fig. 6). The effect of the reverse current flowing toward the west, however, is still visible. But an earlier image of May 30, 1975, does not indicate any reverse current; in fact, there seems to be a very strong current toward the east and northeast (fig. 7).

Two other Landsat-1 images, which the author has seen but not studied in detail, indicate a dominantly northeast-flowing current in July (July 27, 1972), and a dominant west-flowing current in November (November 15, 1972).

DISCUSSION

Successive observations of June 16 and 17, 1975, indicate that plume shapes, hence coastal currents, are variable on almost a daily basis. The influence of two opposing currents seems to change in daily, two-weekly, monthly, and probably also seasonal periods. A well-organized sampling experiment, therefore, must take this fact into careful consideration. Available measurements of sea current (table 1), wind directions and velocities (table 2), and river discharges (table 3), for the relevant dates have been obtained through the courtesy of the Naval Oceanographic Research Institute (SHOD) and the State Water Research Institute (DSI) of Turkey.

Measured current directions for the area of the Sakarya plume conform with the east-flowing current of the sea surface, as already observed on the images. It is interesting, however, to note that no west-flowing current has been detected at depths of 20 m, 50 m, and 100 m. This may be due to the "bulk" nature of the information on the average current distribution, as opposed to the more precise nature of the image evaluation, where movements in sublayers of the ocean may also be detectable.

Wind velocities and directions (table 2) do not seem to correlate well with the observed current directions (figs. 5, 6, 7). This may be due to the inertia of the sea currents, which are the resultants of a number of forces that set large water masses into motion, of which the direction, velocity, and duration of wind are only a few. On the other hand, within the thin atmosphere, wind directions readily and easily change several times a day. Only on images which were obtained at times when strong winds had been blowing above the surface does there seem to be an agreement between the surface current and the wind direction, a condition noted particularly at Ereğli meteorological station, which is situated on the headland which protrudes into the Black Sea (fig. 5). On the May 30, 1975, scene, a strong eastward-blowing wind bends the plumes strongly to the east (fig. 7), and no trace of a west-flowing current can be observed. However, on the November 15, 1972, scene, a strong westward-blowing wind (table 2) shifts the Sakarya plume strongly to the west, obliterating any trace of an east-flowing current. It seems

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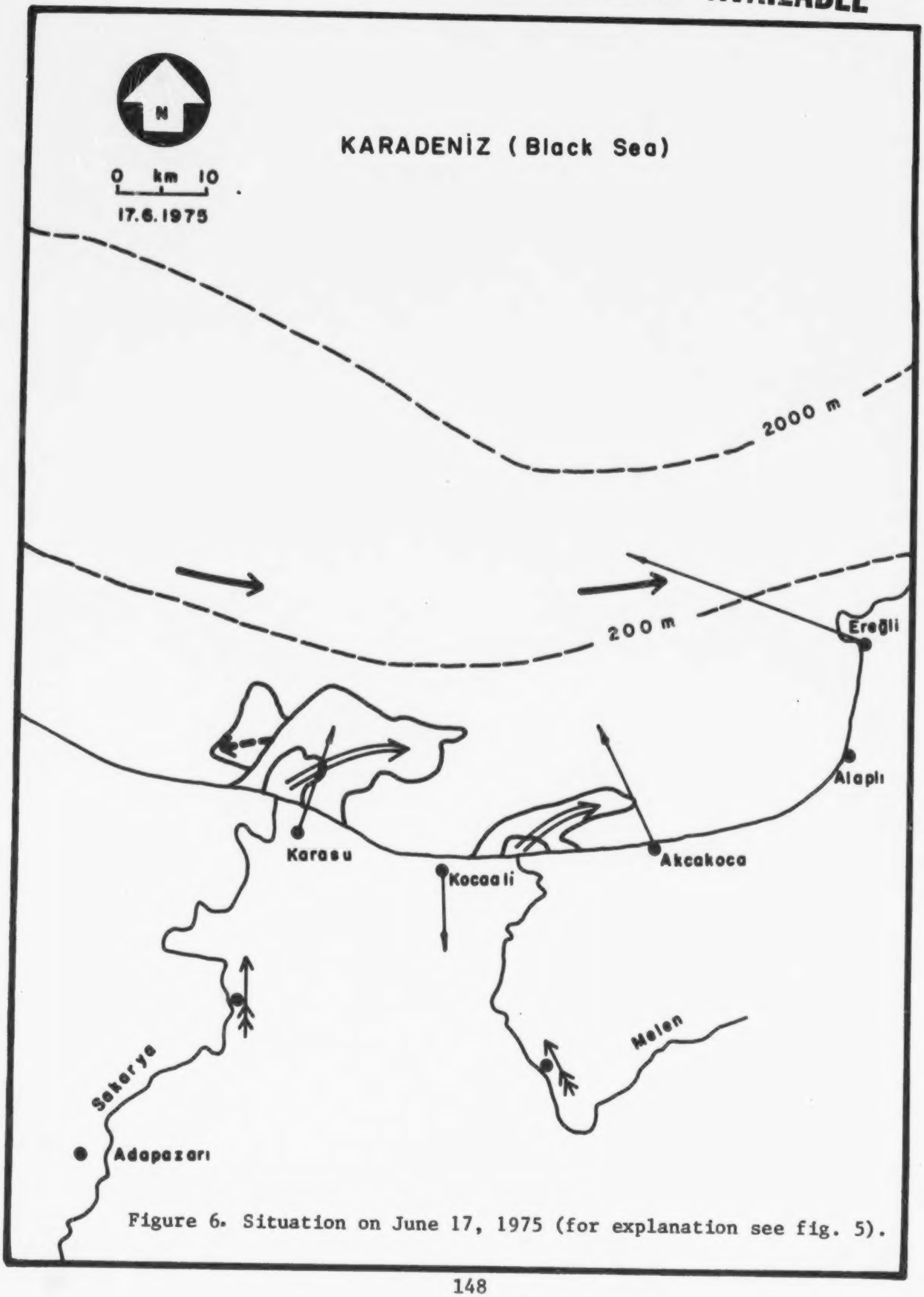

Figure 6. Situation on June 17, 1975 (for explanation see fig. 5).

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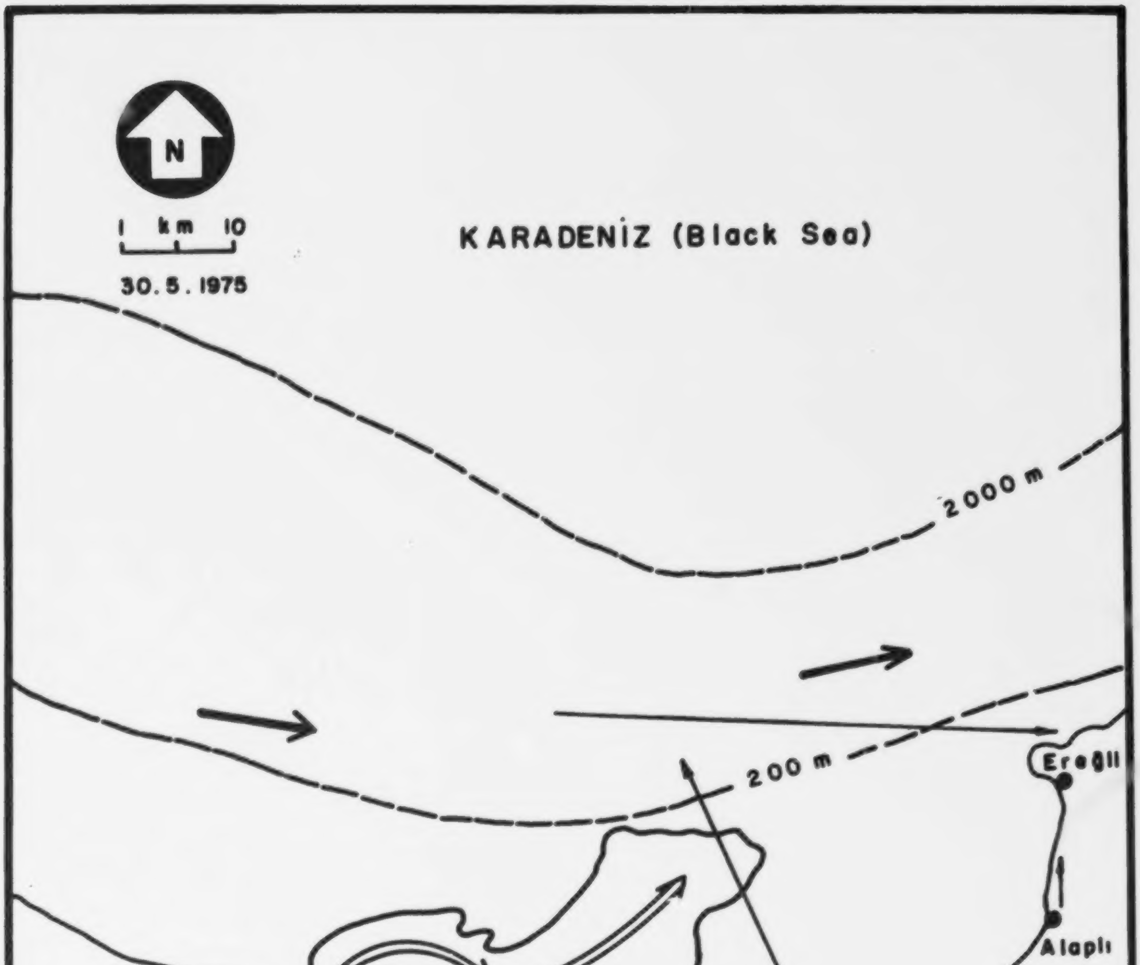

Figure 7. Situation on June 30, 1975 (for explanation see fig. 5).

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that the directions, velocities, and durations of winds recorded by a station well out into the sea, over a period of 48 hours prior to the time of image formation, would yield much better information for correlation, than real time ground-data measurements taken along with the image itself.

The data on river discharges (table 3) indicate interesting, as well as expected, correlation between sizes of plumes and amounts of discharge and/or average stream velocity (cf. table 3 and figs. 5, 6, 7).

Table 1. Sea-current flow velocities on the Black Sea coast of northwest Turkey, for the month of June. (Directions as indicated on figures 5, 6, and 7 are generally toward the east or northeast, parallel to the coastline).

	Current velocities	
Depth (meters)	knots	m/s
0 (Surface)	0.03	0.015
20	0.03	0.015
50	0.03	0.015
100	0.02	0.010

Table 2. Wind directions and velocities (m/sec) at various meteorological stations on relevant dates, at about 08.00 GMT. (Directions indicate the origin of the wind.)

	1972		1975		
Meteorological stations	July 27	Nov. 15	May 30	June 16	June 17
Karasu	N 3.0	NW 3.0	NE 1.0	NE 7.0	SW 2.0
Kocaali	NE 3.0	NE 2.0	NE 1.0	NE 2.0	NE 2.0
Akcakoca*	NNE 3.4	SSE 3.3	SSE 3.7	NNE 4.1	SSE 3.1
Alapli	SW 2.0	SW 1.0	--	N 3.0	S 1.0
Ereğli*	E 7.7	ESE 10.1	W 8.8	NE 7.7	ESE 5.7
Zonguldak*	NW 5.8	ESE 6.3	WNW 5.1	N 8.1	WNW 4.9
Hisarönü	NE 1.0	NE 1.0	NE 1.0	NE 1.0	NE 2.0

* Stations having reliable records.

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Table 3. River discharges (m^3/s) at various stations on or close to the relevant dates.

	1972		1975		
Stream	July 27	Nov. 15	May 30	June 16	June 17
Sakarya	95.8	165.5	172.0	152.0	121.0
Melen	17.3	67.0	37.2	26.5	25.0
Filyos	54.5	184.0	175.0	88.4	82.8
Bartınsuyu	4.0	39.5	20.7	6.0	5.2

CONCLUSIONS

In conclusion, it appears that, at least during certain times of the year, there seem to be two opposing currents with the upper 30 meters of the sea along the Black Sea coast of northwest Turkey. The upper (surface) current flows toward the east and northeast, parallel to the coast, while the lower (subsurface) current flows in the opposite direction, producing corkscrew-shaped plumes. The surface current may change direction under strong wind conditions over long periods, but nothing can be said on what happens to the subsurface current during these times. As the plumes are primarily affected by the surface currents, at such times they are of limited use for detection of the subsurface current behavior.

It can be stated that the synoptic views provided by Landsat MSS images make possible rapid, semiquantitative studies of coastal water movements over wide areas of the sea. The different penetration depths of the different wavelength bands provide an opportunity to construct a three-dimensional view of a plume, thus allowing one to interpret and compare surface and near-surface currents of an area simultaneously. If these capabilities could be combined with sufficiently repetitive coverage and with oceanographic, hydrographic, and meteorologic ground data, extremely valuable information would be available at a fraction of the cost and effort of more conventional methods now used to achieve a similar level of information. However, it is clear that, some detailed organization and planning must be done prior to embarking on such a project, as it involves the cooperation of several national and/or international offices.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of the Central Treaty Organization (CENTO) in providing the images, the Minerals Research and Exploration (MTA) Institute for help with reproduction of the images, and the State Water Research Institute (DSI) as well as the State Hydroelectric Research Institute (EIE) for supplying stream information, the Naval Oceanographic Research Institute (SHOD) for providing coastal current data and the Meteorological Office for wind data.

COPPER EXPLORATION RESEARCH IN IRAN, USING LANDSAT DATA

By Howard A. Pohn
U.S. Geological Survey
Box 25046, Denver Federal Center, Denver, Colorado, 80225

ABSTRACT

A combination of computer processing and color-ratio compositing of Landsat data has been used to locate areas of iron-oxide stain (commonly associated with rock alteration associated with porphyry-copper deposits) in the mineralized belt west of Kerman, Iran. The data-processing technique, which is based on a system developed by Rowan and others (1974), uses the principle of computer enhancement of small differences in reflectivity in the visible and near-infrared as they appear in the various Landsat bands.

Multispectral scanner (MSS) bands are stretched and ratioed, picture element by picture element, and each ratio is printed in a different color using a diazo process to produce individual color films. The color combinations used in the study were cyan for the ratio of band 4 to band 5, yellow for 5 to 6, and magenta for 6 to 7. In this composite image, areas of iron-oxide stain appear green.

The color composite was compared to 1:100,000-scale geologic maps of the Kerman region to evaluate the technique for locating mineral deposits (Geol. Survey of Iran, 1973). Of 122 areas which appeared green on the composite, 17 were found to contain known copper deposits and 3 of these contain copper mines. Included among the mines was Sar Cheshmeh, one of the dozen largest copper mines in the world.

The green areas are not apparent on the images of any of the individual bands, ratios, or false-color infrared composites.

It is likely that this technique can, with careful field checking, guide exploration for deposits of copper and other minerals in altered areas.

INTRODUCTION

The technique of using stretched color-ratio composite images for locating areas of iron-oxide stain (commonly alteration areas) was developed by Rowan and others (1974). This technique utilizes the principle that the reflection properties of iron-oxide differ subtly from the reflection properties of other geologic materials in the four

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Landsat bands (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 um) and that these small differences can be enhanced by stretching, ratioing, and color-compositing the data.

It has been shown by Rowan and others (1974) that the individual Landsat bands cannot be used to descriminate areas of iron-oxide stain, nor can the presence of this stain be enhanced on a Landsat MSS image by any combination of bands in a normal additive color display. Areas of intensive red stain may appear yellow on false color infrared images, but this is not entirely reliable.

The technique of stretched color-ratio compositing has been applied to a part of a Landsat-1 image of south-central Iran (fig. 1). The region is part of the mineralized volcanic belt that extends from the northwest to the southeast part of the country. Numerous copper mines, including the Sar Cheshmeh open-pit mine, are located along this belt.

An examination of the Landsat images of the mineralized volcanic belt showed many areas of good potential for possible study, but it was felt that the best regions would be those which had some known copper deposits and also had evidence of deeply eroded volcanic rocks. The model advanced by Sillitoe (1973), which links subduction along plate margins, volcanoes, and associated porphyry-copper deposits, was felt to be appropriate for use in the volcanic belt, and the selection of the region was based on the presence of highly dissected volcanoes, apparent deep erosion, and the presence of known copper deposits.

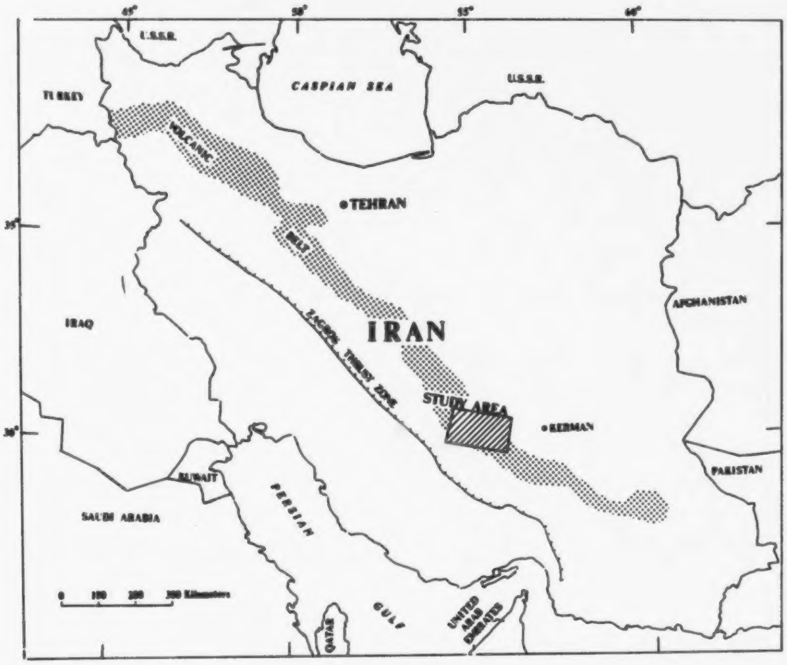

Figure 1. Index map showing study area in Iran.

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ACKNOWLEDGMENTS

I would like to express my gratitude to the following people for their cooperation and assistance in producing this report: Gary Raines, for his assistance in running the computer programs; Philip Guild, for discussions on mineral occurrences in Iran; Dr. Reza Assefi, for permission to use parts of the Geological Survey of Iran geologic map of the Kerman region (Geol. Survey Iran, 1973); and, most especially, to Robert G. Schmidt, for discussions on copper deposits and permission to use his field notes on sites he visited in the study area.

GEOLOGY OF THE REGION

The region under study is located near the center of an elongate NNW-SSE-trending mountain belt that extends from Turkey to Iranian Baluchistan and is parallel to the Zagros thrust zone (fig. 1). The volcanic and sedimentary rocks along this belt are mainly of Cretaceous and Tertiary age and have been folded and faulted.

Because of the aridity of the area, soil profiles are generally poorly developed and vegetation is sparse. Only the tops of mountains and the floors of alluviated valleys contain significant vegetation. Agricultural developments in the region are confined to Rafsanjan and Shahr-e-Babek (fig. 2).

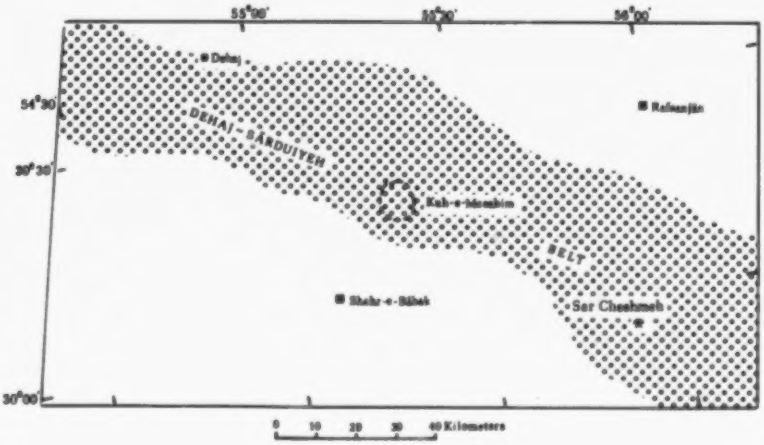

Figure 2. Study area showing the Dehaj-Sarduiyeh volcanic belt and Kuh-e-Mosahim caldera.

Rock units.--The most extensively exposed rock units within the region are lower Eocene flysch, conglomerate, and red sandstone and Eocene, Miocene, and Pliocene andesite, basalt, and rhyolite. These units occupy more than 90 percent of the area not covered by alluvium. The combined thickness of these units exceeds 6,000 meters (Dimitrijevic, 1973).

Deeply dissected upper Tertiary andesitic extrusives, pyroclastics, and other volcanic rocks are common in the northwest part of the region. Flows, cones, and at least one large caldera, (Kuh-e-Mosahim) also of late Tertiary age, have been identified in the region.

Geologic structure.--The study area is included in the Dehaj-Sarduiyeh belt (fig. 2). This belt consists of a long flysch trough composed of several individual sedimentary basins to the northeast. During the Late Cretaceous and early Eocene a thick sedimentary sequence accumulated in the trough. An intensive folding phase that produced a conspicuous unconformity between the sediments and the subsequent volcanics took place by the end of the early Eocene.

From the early Eocene until the end of the Eocene, the Dehaj-Sarduiyeh belt was part of an extensive continental fissure that extended from the Balkan Peninsula through Turkey and northern Iran to the southeast part of the study area. More than 300,000 cubic kilometers (km^3) of volcanic material were emplaced in and around the study area during the Eocene.

In contrast to the intensively folded lower Eocene section, the later Eocene volcanic rocks form broad gentle folds (Dimitrijevic, 1973).

The Sar Cheshmeh prophyry-copper deposits

The Sar Cheshmeh porphyry-copper deposit is the largest in Iran and one of the largest porphyry-copper deposits in the world. The deposit, which has dimensions of 2,000 m by 900 m, is centered on the upper Tertiary Sar Cheshmeh granodiorite porphyry stock and is surrounded by Eocene pyroclastic rocks that are intercalated with pyroxene trachyandesite and trachybasalt lava flows. The relatively soft altered rocks in the stock have been eroded to form a basin that is drained by the Sar Cheshmeh stream (Geol. Survey Iran, 1973; Waterman and Hamilton, 1975).

The orebody occurs in the granodiorite porphyry and peripheral Tertiary volcanic rocks. The deposit contains at least 4.5×10^6 tons of ore that contain an average of 1.13 percent copper with a 0.4 percent cutoff (Waterman and Hamilton, 1975).

INTERPRETATION OF THE IMAGES

Standard MSS images

The standard MSS images as derived from the tapes obtained from Goddard Spaceflight Center are of very low contrast (fig. 3) and yield little information compared to geologic maps of the region (fig. 4). The only unit which can be recognized with certainty is Unit EB, the Bahr Aseman Complex located at A and B (figs. 3 and 4). This unit is composed of pyroclastic rocks, trachyandesite, tuffaceous sandstone, and conglomerate of early Eocene age. It can be seen from figure 3 that the complex has a low reflectivity in bands 5, 6, and 7, and a moderately low reflectivity in band 4. Even though this unit is readily distinguished from the adjacent units, it appears similar to units of low reflectivity elsewhere in the region.

Areas of eroded volcanic rocks at location C (fig. 3) are discernible because of their geomorphic expression rather than by any reflectivity difference.

Two-percent linearly-stretched MSS images

In order to form a 2 percent linear stretch, a histogram is made of the scene which plots number of pixels (picture elements) versus digital number (DN--gray levels in the image, from 0-255). The lightest and darkest 2 percent of pixels are discarded and the remaining 96 percent of the pixels are arranged in a linear fashion over the entire 256 gray levels. This procedure has the effect of increasing the contrast in middle tones.

The major advantage of the stretched MSS images is the increase in contrast that results from the stretching process. No increased discrimination of lithologic units can be observed from the stretched images, but considerable geomorphic and structural information is apparent. Numerous folds (fig. 5; points A, B, and C) as well as a circular structure at point D can be seen on all four bands. In addition, the folds at E suggest the presence of what may be the western limb of the Shan Abad anticline (Dimitrijevic, 1973). A large unmapped throughgoing lineament which is probably a continuation of a small mapped fault can be seen at F-F'.

Stretched-ratio images

In the ratio procedure, two spectral bands are divided pixel by pixel. The effect is to suppress the differences in reflectivity due to varying slopes; thus materials with a similar albedo but different topographic expression will appear to be similar in a ratio image.

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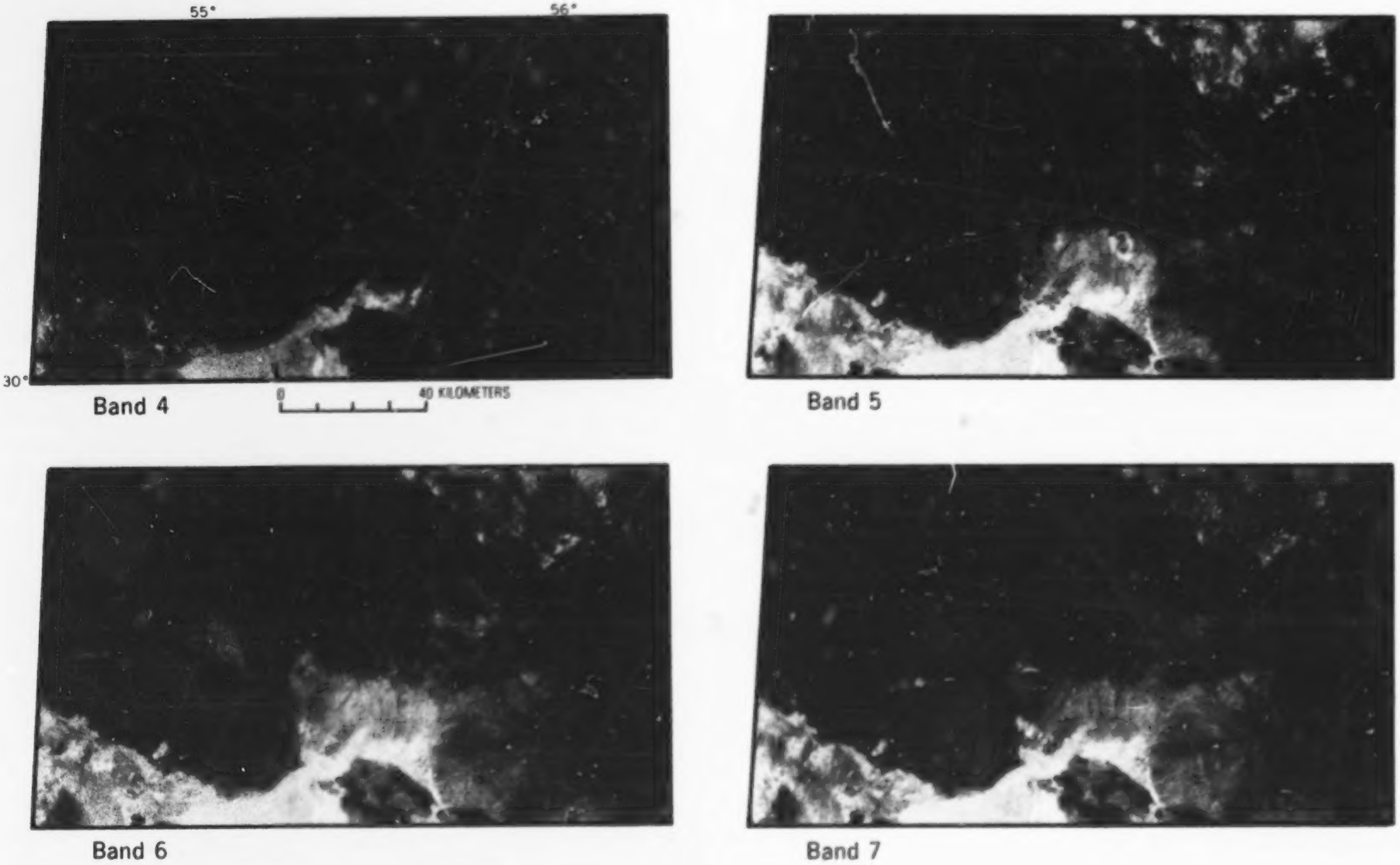

Band 4

Band 5

Band 6

Band 7

Figure 3. Standard Landsat MSS images from the tapes from Goddard Spaceflight Center. A and B, Bahr Asemān complex composed of pyroclastic rocks, trachyandesite, tuffaceous sandstone, and conglomerate; C, Dehaj-type subvolcanic intrusives.

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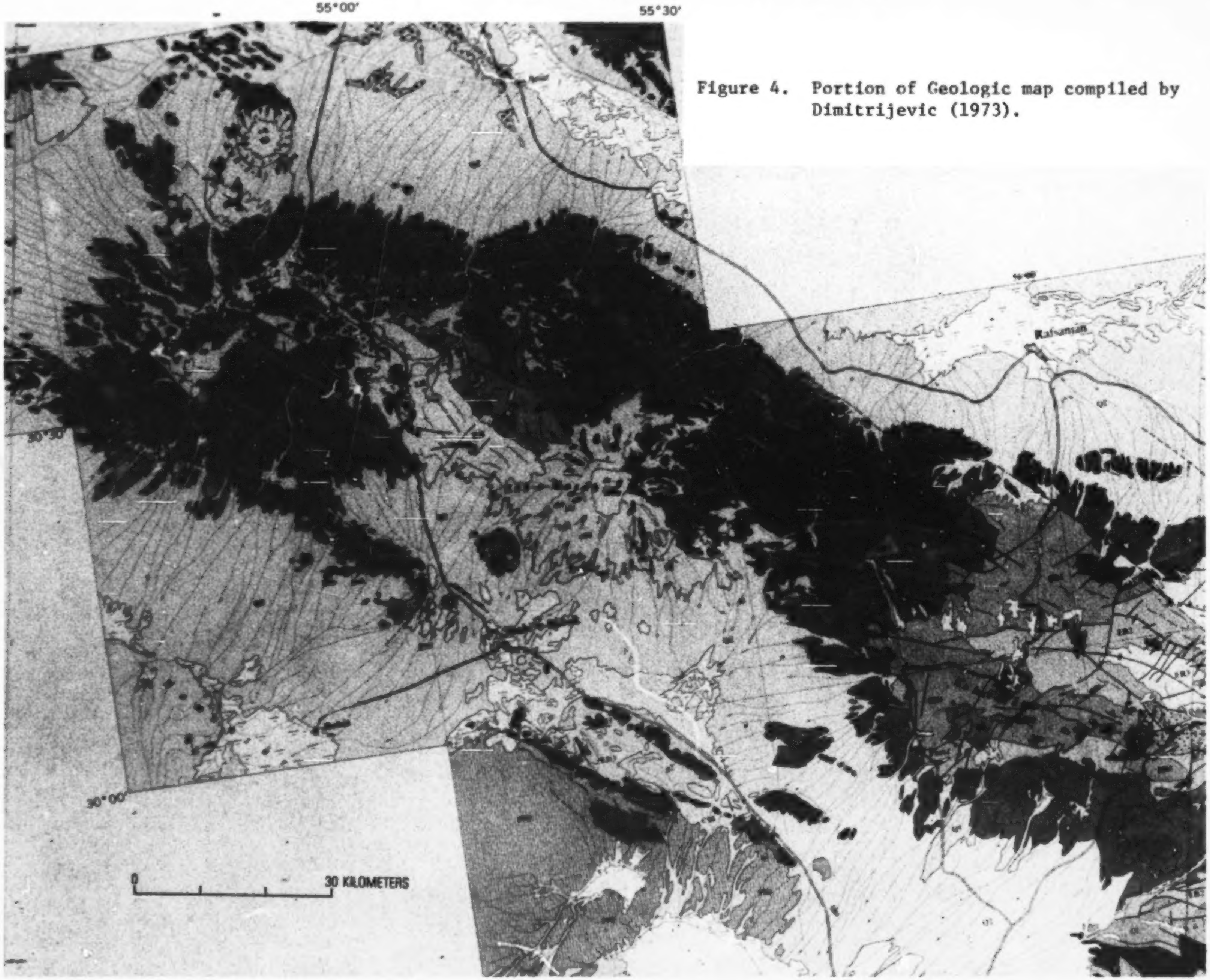
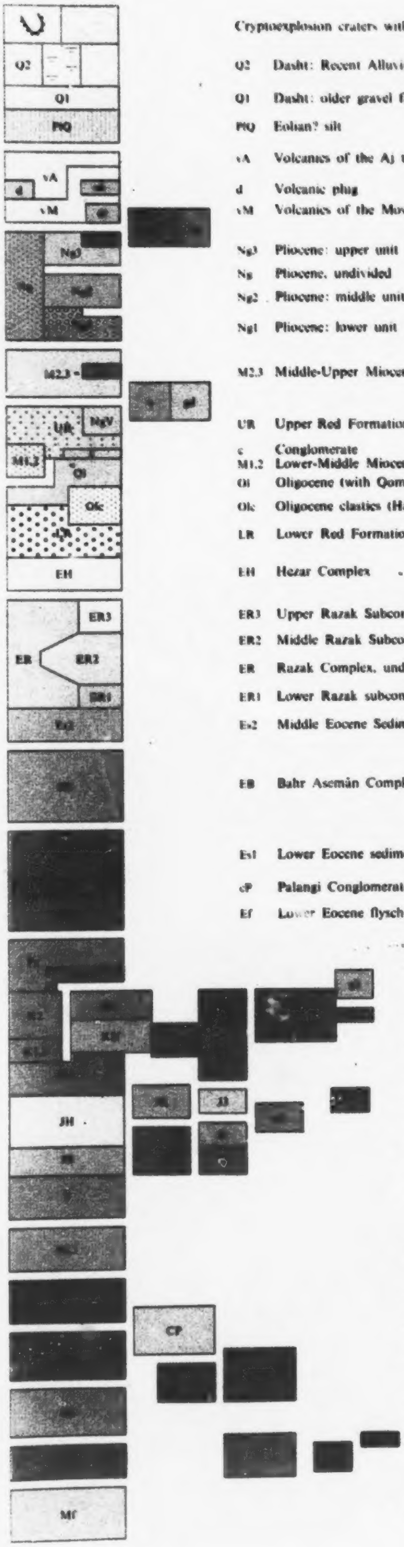


Figure 4. Portion of Geologic map compiled by Dimitrijevic (1973).

L E G E N D

Figure 4a.

All units in legend do not appear on Figure 4.



Cryptoexplosion craters with debris ; Sand flat

Q2 Dasht: Recent Alluvium and younger gravel fans ; Clay flat : Kavir (salt flat)

Q1 Dasht : older gravel fans

PlQ Eolian? silt

vA Volcanics of the Aj type

d Volcanic plug
vM Volcanics of the Mosahim type

ab Andesite-basalt lava flows
di Fine grained diorite in the volcanic plug
da Dehaj type subvolcanic intrusives ; dp - Pyroclastics
b Basalt lava flow

Ng3 Pliocene : upper unit
Ng Pliocene, undivided
Ng2 Pliocene : middle unit
Ng1 Pliocene : lower unit

M2.3 Middle-Upper Miocene

an Andesite lava flows
a Subvolcanics of the Kuh-e-Panj type
gd Granodiorite and accompanying shallow intrusives of the Jebal Barez type
NgV Neogene volcanics (Kuh-e-Lālehzār)

UR Upper Red Formation

c Conglomerate
M1.2 Lower-Middle Miocene
Ol Oligocene (with Qom and Chahar Gonbad Formations)
Olc Oligocene clastics (Hana)
LR Lower Red Formation

EH Hezar Complex

ER3 Upper Razak Subcomplex
ER2 Middle Razak Subcomplex
ER Razak Complex, undivided
ER1 Lower Razak subcomplex
Es2 Middle Eocene Sedimentary Complex

EB Bahr Asemān Complex

Es1 Lower Eocene sedimentary complex
cP Palangi Conglomerate
Ef Lower Eocene flysch

Pg Paleogene
cK Kermān conglomerate

K2 Upper Cretaceous
K1.2 Albian-Cenomanian
K1 Lower Cretaceous
JK Jurassic-Cretaceous (Sirjān)
JH Hojedk Formation
J Jurassic, undivided
Jm Jurassic?, metamorphosed
JB Bādāmu Formation

K2l Upper Cretaceous reef limestone (Baghin sheet)
Ksf Senonian flysch ;
K2f Cenomanian-Turonian flysch
KC Conglomerate (Baghin and Rafsanjan 2 sheets)
K1l Lower Cretaceous reef limestone

J3 Upper Jurassic (Esfandaqeh)
J2 Middle Jurassic sediments (Esfandaqeh)
J2v Middle Jurassic volcanics (Esfandaqeh)

g2 Acidic intrusives in the Coloured Melange
CM Coloured Melange
Se Serpentinite
CM' Layered base of the Coloured Melange

db2 Diabase
g1 Pre-Tertiary granitic rocks (Kuh-e-Khunrang type)

T Triassic and Rhaeto-Liassic (with question mark : supposed)

P2.3 Middle-Upper Permian

P1 Lower Permian

CP Permo-Carboniferous

SD Kereshk Group (Silurian-Devonian)

Kh Khaju Complex
db1 Metamorphic diabase

OS Buj Formatior rdovician — Silurian)

Є Rizu Series (Infracambrian)

m Metamorphics of unknown age

Se1 Metamorphosed serpentinite
gb Gabbro

Mf Morād series

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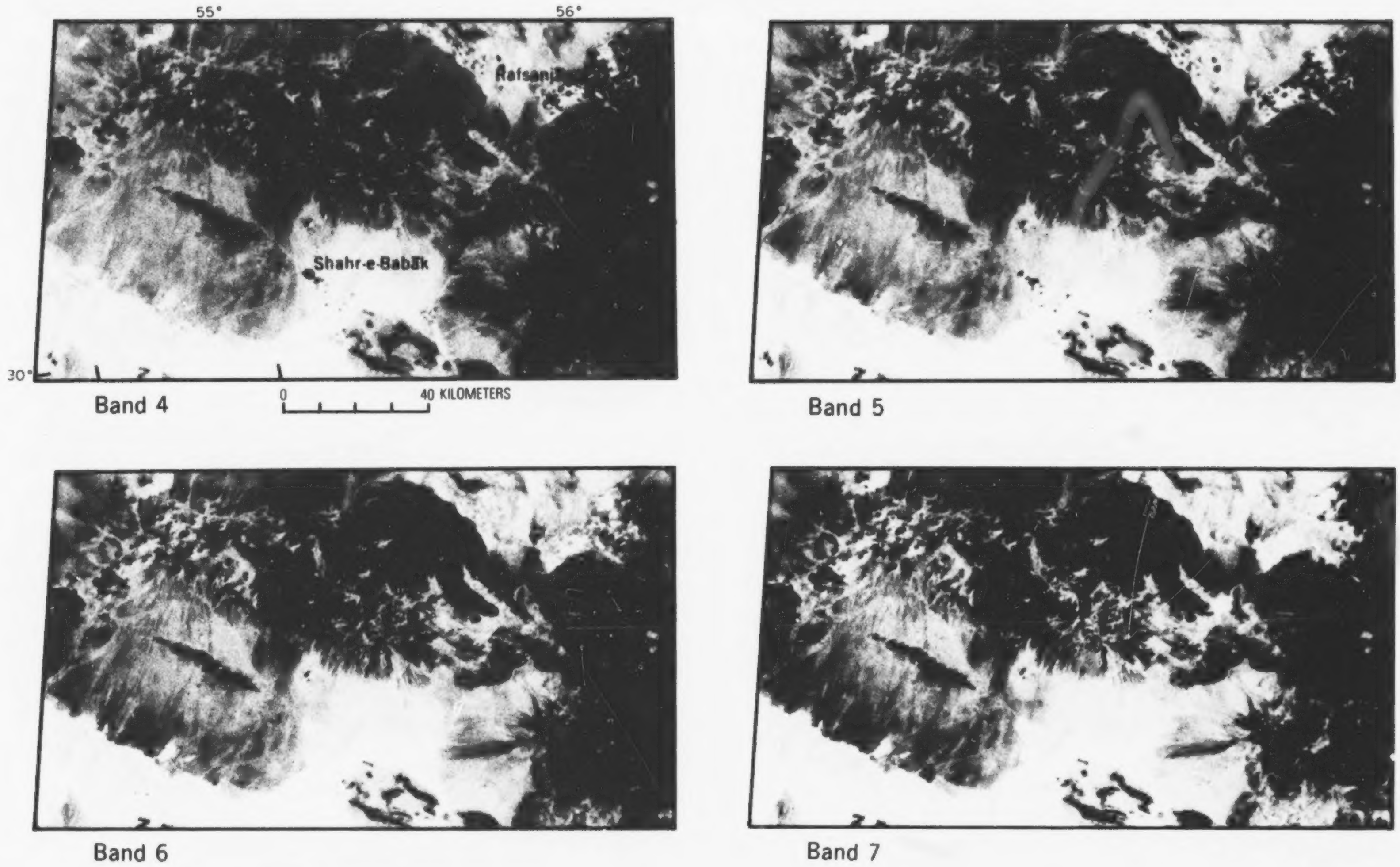

Band 4

Band 5

Band 6

Band 7

Figure 5. 2% linearly-stretched Landsat MSS images of the study area. Points A, B, and C indicate folds that are more conspicuous on the stretched images; D indicates a circular structure; E is possible western limb of the Shan Ābād anticline; F-F', linear feature, which probably represents a fault.

In the stretched-ratio images, the observer can begin to see the advantages of the processing for locating areas of iron-oxide stain. Many of the darkest areas in the image of the 4 to 5 ratio (fig. 5, areas labeled A) are areas of iron-oxide stain. At this stage in the processing, however, some ambiguity remains between the stained areas and some of the other units.

The brightest areas in the individual ratios (fig. 6, points B and C) correspond to talus cones on the flanks of Aj-type volcanoes of Pliocene age (Dimitrijevic, 1973). Volcanic rocks are in general quite light in the 4 to 5 ratio but can be confused with vegetation in this single ratio image. When all three ratio images (4 to 5, 5 to 6, 6 to 7) are examined, the ambiguity is resolved because the volcanic rocks are light in all three images, whereas the vegetation is the darkest feature in the latter two ratio images. Sedimentary rocks are of intermediate brightness in all three images.

Color-ratio composite image

The color-ratio composite image was produced by using the diazo process for making single-color transparencies of each of the previously mentioned ratios. The combination selected for this study was cyan for the ratio of band 4 to band 5, yellow for 5 to 6, and magenta for 6 to 7.

The reason that the particular color combination of diazo foils was chosen is as follows: Iron-oxide stain is very nearly the darkest feature in band 4, hence the ratio of 4 to 5 is very low. When this ratio is printed on cyan diazo foil it produces a large contribution of cyan to the image. Similarly, iron-oxide stain in the band 5 image is dark and thus the 5 to 6 ratio is dark and when printed on yellow, diazo produces an intense image. Bands 6 and 7 are both relatively light, and the ratio is higher than most other materials; therefore, when the ratio 6 to 7 is printed on magenta foil, the resultant image is light in areas of iron-oxide stain.

The contribution of intense cyan and yellow with a minimal contribution of magenta produces a series of green tones in areas of iron-oxide stain.

Although Rowan and others (1974) used blue diazo foil instead of cyan, the final result is nearly the same. Both procedures make use of all four Landsat bands, and the difference appears to be that cyan foil produces a more intense green than does blue foil. (The more intense green might also be due to a difference in the amount of iron oxide or a small difference in the surface mineralogy.)

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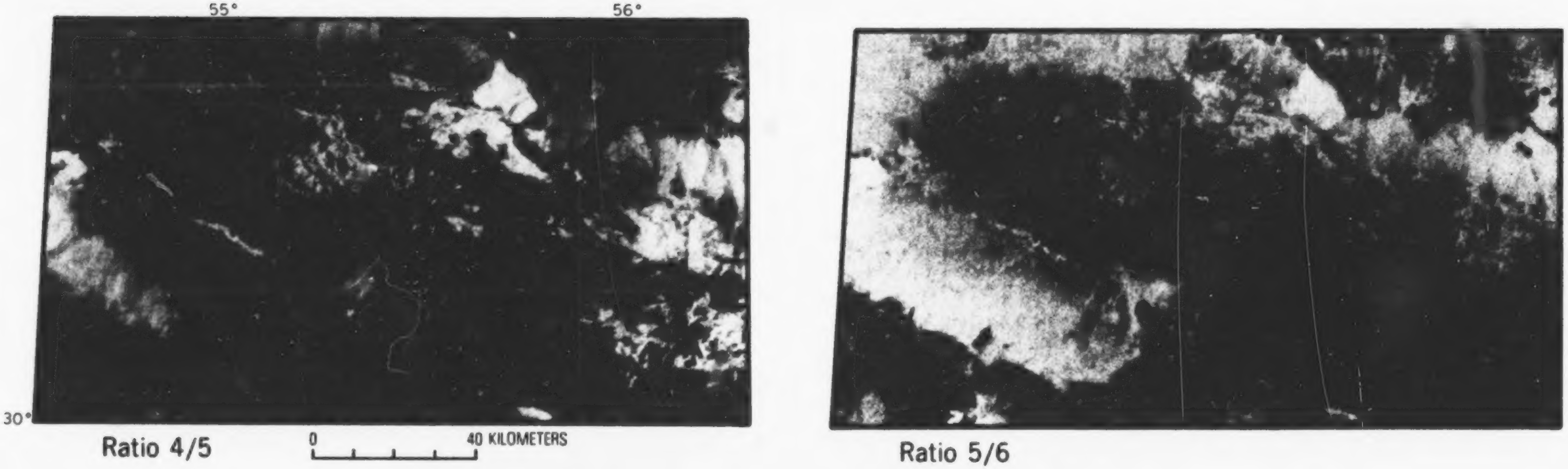
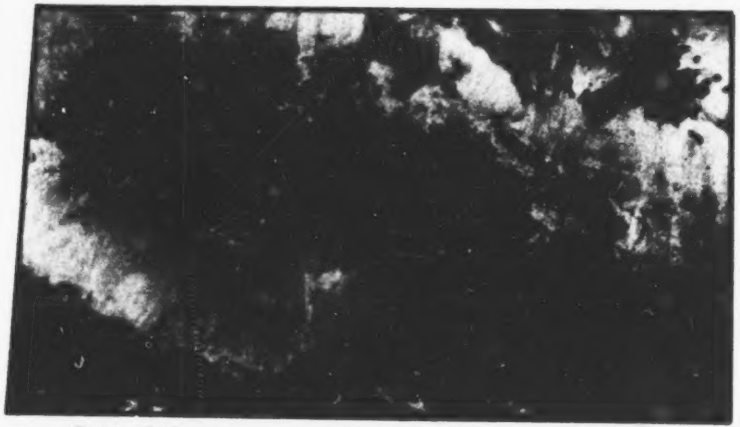


Ratio 4/5

Ratio 5/6



Ratio 6/7

Figure 6. Stretched-ratio images. Point A indicates dark areas on ratio 4/5 image, which represent iron-oxide stain; B and C are talus cones on volcanoes.

ANALYSIS OF THE COLOR-RATIO COMPOSITE IMAGE

The color-ratio composite image (fig. 6) was compared in detail to the 1:100,000 geologic maps of the region (Dimitrijevic, 1973) to determine the correlation of rock units with color. Most volcanic rocks appear to be white, brown, or reddish tan on the color-ratio composite image (fig. 7; A, B). These areas are easily distinguished from vegetation (fig. 7; C, D), which is a deep orange to a vivid red. Sedimentary rocks are generally pale purple to purplish green (this latter color is produced where the sedimentary rocks are stained with iron oxide (fig. 7; E)), but they may be white, or in the case where unconsolidated sediments are derived locally, they are the color of the source materials. Sand flats (fig. 7; F) are blue. Most of the other rock types are variable in color and cannot be identified unambiguously.

The most striking features in the color-ratio composite are the green areas, which represent areas where the rocks are stained with iron oxide (commonly limonite). These areas are distributed throughout the volcanic belt and constitute perhaps one percent of the area of the image. The green tones range from pale yellow green to a dark purplish green (fig. 7; G, H, I). This is attibuted to a combination of the percentage of iron oxide and the nature of the rocks that have been stained. No correlation with rock type is apparent.

Although Rowan and others (1974) found that areas of surface alteration could appear as colors other than green (notably brown to red-brown), no attenpt is made in this study to determine the nature of alteration or staining which produced colors other than green.

On the image, 122 areas were visually determined to be green. These were compared to the 1:100,000-scale geologic maps on which known deposits of copper were located. It was found that 17 of the green areas contained known copper deposits. Three of these areas correspond to the copper mines at Sar Cheshmeh, Palangi, and Lachah (fig. 7; J, K, and L, respectively), although the green area at Palangi was due to a surface exposure of red conglomerate and was not related to the deposit itself. The green area at Sar Cheshmeh was found to correspond exactly to the area of altered granodoirite that represents the boundaries of the deposit (Waterman and Hamilton, 1975).

Structural interpretations from the color-ratio composite

Several features on the color-ratio composite might be directly related to structural geology. As mentioned previously, some of these features can be seen to varying degrees on the other computer-processed images, but are seen best in the color-ratio composite. This may be due to the presence of different rock types on either side of the lineament, or to different textures of materials within the lineament zone.

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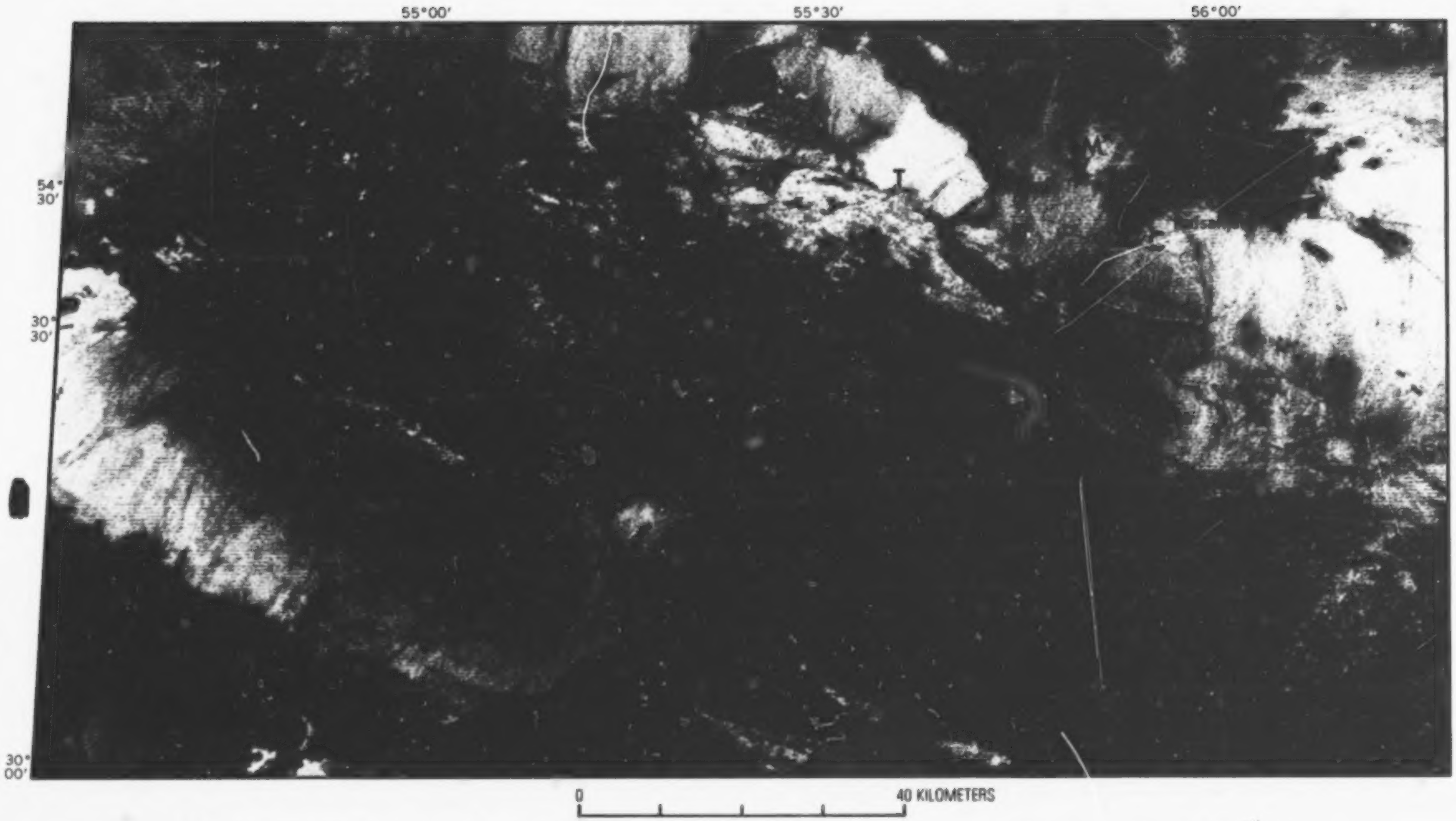

Figure 7. Color-stretched ratio composite image, in which ratio 4/5 is presented in cyan, 5/6 in yellow, and 6/7 in magenta. Points A and B indicate volcanics; C and D, vegetation; E, limonite-stained sediments; F, sand flats; G, H, and I, limonite-stained rocks; J, K, and L, limonite staining at the Sar Cheshmeh, Palangi, and Lacheh copper mines, respectively; M-M', lineament which probably represents a fault; N, apparent anticlinal folds which may be the western limb of the Shan Ābād anticline; O, eastern limb of the Shan Ābād anticline; P, field location of dark andesite; Q, field location of gypsiferous red mudstone; R, field location of possible volcanogenic sulfide; S, field location of possible volcanogenic sulfide with evidence of some copper mineralization; T, field location of slag heaps and copper mineralization; U, field location of slag.

A second set of features is associated with the apparent anticlinal folds at N on figure 7. These seem to be the northwest end of a doubly plunging anticline (the Shan Abad anticline, Dimitrijevic, 1973) whose southeast terminus is at O. The west end of the anticline is not shown on any of the existing geologic maps.

Analysis of lineaments in the study area

One thousand twenty-nine lineaments were drawn on the 2 percent stretch images and on the color-ratio composite. A plot was made of the 158 lineaments whose length exceeded 5 km. It can be seen from figure 8 that two major orthogonal sets dominate the plot. The first set (with peaks at N. 50°-55° W., and N. 35°-40°E.) is parallel and perpendicular, respectively, to the strike of the Zagros thrust. The second set (with peaks at N. 5°-10°W., and N. 75°-80°E.) is at a 45° angle to the direction of the Zagros thrust and is parallel and perpendicular to the strike of the thrust fault that represents the western boundary of the Lut block (a micro-continental plate just east of the study area).

Because of the structural complexity caused by the interaction of the Zagros thrust and the Lut block, it is impossible to determine whether the peaks (other than one parallel to the Zagros) are due to stresses associated with the Zagros thrust, the Lut block, or a combination of both.

An alternate possibility is that the N. 5°-10°W. and N. 75°-80° E. lineaments may be part of an older fault or joint set which was formed in the central Iranian block and that the N. 50°-55° W. and N. 35°-40° E. lineaments are an overprint caused by the episode of thrusting toward the Zagros.

The structure rose was replotted for lineaments to the east and west of the linear feature at M-M' on figure 7. These new roses (fig. 9, b) indicate a significant difference in structural domains on either side of the lineament and add strength to the position that the lineament is, in fact, a fault.

The analysis of the lineaments shows no striking correlation of lineament interactions with copper deposits.

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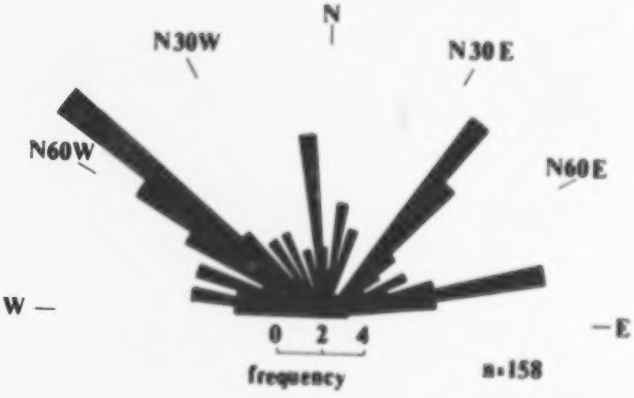

Figure 8. Structure rose of the study area showing the presence of two orthogonal lineament sets.

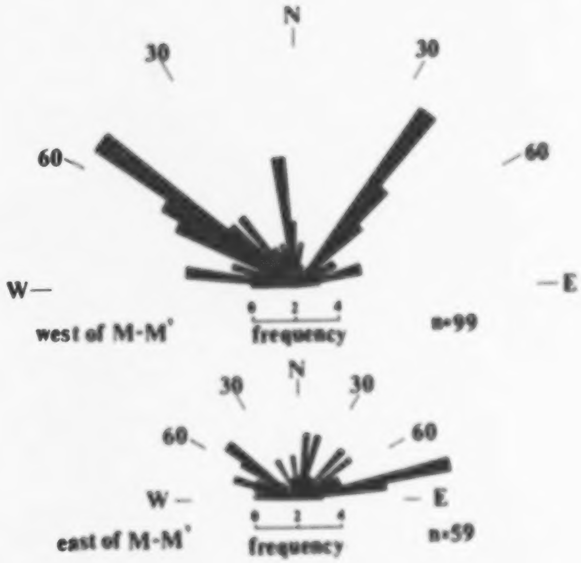

Figure 9. Structure rose of lineaments west of the lineament M-M' (fig. 7).

Field investigations

In the spring of 1976, while in the region under study with some members of the Geological Survey of Iran, I had the opportunity to visit some of the areas that appeared green on the color-ratio composite. The primary purpose of these brief field excursions was to look for copper mineralization, and no detailed investigations were conducted at that time. R. G. Schmidt of the U.S. Geological Survey also visited some of the areas in the fall of 1976 and has generously permitted me to make use of his more detailed field observations of several of the areas. Throughout this section, the observations by R. G. Schmidt are in quotation marks. Supplementary observations made on my field trip are not.

1. The Palangi Mine (K of fig. 7): "The rock at the mine is probably Eocene flysch. The copper mineralization in the 'mine' is in dark andesite with rather little hydrothermal rock alteration, certainly no pervasive rock alteration. The copper mineralization bears no relationship to the color ratio 'anomalies'."

It was my observation that the rock above the mine was red conglomerate and hence the presence of the anomaly.

2. Site P (fig. 7): "Very amygdaloidal dark purplish andesite. The amygdules are mostly less than 2 cm diameter but a few are as much as 5 cm. They are all filled with a hard white zeolite."

3. Site Q (fig. 7): "The outcrop area is north-dipping gypsiferous red mudstones that produce some discontinuous red-stained patches of soil and rock debris."

4. Site R (fig. 7): "The rocks in this area have the overall appearance of a stratified sequence consisting of tuffs, volcanic conglomerates, perhaps some flows and some rocks of undetermined origin. The general succession, from north to south, is pale gray to white barren felsic tuff, sulfide-bearing light-gray siliceous rock, and dark-gray andesitic volcanic conglomerate. No rocks of certain intrusive origin were seen. Only sparse sulfide was seen in the felsic tuffs except in what is probably a 50-meter thick transition to the overlying sulfide-bearing layer. The sulfide-bearing strata are 300 m thick and are of indeterminate origin, but I presume that they were siliceous tuff. The primary sulfide content is in the 3-5 percent range and most of the sulfide appears to be pyrite. There are scattered occurrences of dark-red hematite crusts in the voids left by leaching of the sulfide grains that resemble the iron oxide remaining after oxidation of chalcocite, suggesting that some secondary enrichment of copper may have taken place. No specific copper minerals were identified. The sequence, rock alteration, and sulfide mineralization fit the model of a volcanogenic deposit."

5. Site S (fig 7): "The sulfide-bearing succession at this location is very similar to the rocks at R. The sulfide-bearing strata appear to be about the same thickness as at R. The sulfide-bearing rock is thoroughly leached and now rather nondescript. I was not able to identify the original rock types. Sparse oxidized mineral stains are present on steep slopes where erosion is rapid, but are lacking elsewhere. No primary sulfide was seen but the general appearance of the abundant limonite staining suggests 5-10 percent pyrite was originally present, perhaps more locally. The area has been tested by diamond drilling--at least 3 holes--and by adits. Geologic features at this site are characteristic of volcanogenic deposits."

In my visit to this site several small pieces of malachite and azurite were found in the stream valley just east of the area described by Schmidt.

6. Site T (fig. 7): The site is composed of a large block (0.25 x 0.5 km) of altered andesite. The surface appears pale pink to orange and is covered with a lag surface of andesite cobbles. Approximately 0.5 km downstream (to the north) there is a slag heap 25 m on a side, and 0.5 km north of the first site is a second slag heap 10 x 30 m. Abundant slag was found in the stream bed, although we found only occasional traces of malachite and azurite. The presence of this slag indicates that sometime in the past, copper was mined near the sites.

7. Site U (fig. 7): The site is a pavement surface 0.5 km on a side in a broad stream valley. The surface is composed of black desert-varnished to dark-red andesites. No copper minerals were found but slag was very common throughout the surface materials.

CONCLUSIONS

This study has shown that stretched color-ratio composite images can be used to indicate possible structural information which may be absent or only weakly present on other types of computer-processed Landsat images.

More importantly, the technique can be used successfully to locate areas of iron-oxide staining that are commonly associated with alteration in areas of porphyry-copper deposits.

In the present study, 14 percent of the areas that appeared green on the color-ratio composite were found to include either copper deposits or copper mines. In addition, several of the sites not designated as copper deposits on the geologic maps (but visited in the field) showed the presence of at least weak copper mineralization. The remaining sites have not yet been visited but should be evaluated in the field as a first step in regional mineral exploration.

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IMAGE MODIFICATION FOR AIDING INTERPRETATION AND ADDITIVE COLOR DISPLAY

By Donald S. Ross
Consultant

ABSTRACT

Modern technology permits collecting data at a much higher rate than it can be turned into usable information. While great strides have been and continue to be made in the machine processing of image data as acquired by the Landsat satellites, nevertheless a heavy dependency must rest on visual interpretation of these images for some time to come. However, many of the urgent tasks of using such images for the inventory, measurement, and monitoring of the earth's resources can be satisfied by skillful visual interpretation. For valid technical reasons, the standard photographic image product from the Landsats (and many other sensors) is not always reproduced in a way that visually displays the full information content.

This paper outlines several photographic techniques, which can be performed with conventional equipment and materials, for enhancing such images, to permit better visual interpretation. Some of these processes parallel results obtainable by computer image processing, viz., contrast stretching, density slicing, addition and subtraction of spectral bands, and suppression of redundant data. Color display and image scale are also discussed.

To implement improved image display, a close collaboration between the user and the reproduction agency is essential.

INTRODUCTION

Today, there are many optical, electronic, and computer techniques to assist in the analysis and computation of data found in images, to convert these data to information which can be used in the earth sciences. Most of these data-extraction techniques, however exotic, were originally based on, and developed from, the experienc knowledge, and skills of those adept at visual photointerpretation.

These methods of image analysis portend the future, because with modern technology we can collect image data at a much higher rate than can be interpreted by human means. This does not mean that in the meantime, we should overlook the basic source where people look at images, interpret their significance, and make decisions based on the information they deduce and infer. There are still many applications where visual interpretation is still more rapid than can be accomplished by machine processing.

This paper is intended only as an outline of several photographic techniques for enhancing images, to aid the analyst in his interpretation. The writer is not an interpreter, and is not able to prescribe specific procedures for solving all the image display problems the discipline specialist encounters. These can best be handled by close cooperation between the interpreter and the organization that reproduces his imagery, to select and develop enhancement processes appropriate to his need.

Properly applied, photographic techniques of image enhancement can greatly extend the area of use for Landsat images, as only simple equipment and conventional materials are required. Users who do not have time for, or access to, image processing by machine methods can take advantage of them with a minimum outlay on capital equipment.

TECHNICAL DISCUSSION

The photo image and the interpreter

The main tool used by the earth-resources community is the photographic image: a representation of the earth scene as recorded by the electronic sensor or photographic camera. By visual examination the interpreter, in consultation with his memory banks, arrives at decisions applicable to his special field concerning the information he has deduced or inferred from the image. Such decisions can be based only on what the interpreter can see, recognize in the image, and relate to his technical understanding and reasoning process.

While quantitative measurements can be made in the image (geometry, distance, density, etc.), visual analysis is primarily founded on qualitative, subjective grounds. This is not necessarily disadvantageous, because a very large proportion of earth resources image analysis tasks can be, and are, satisfied by visual interpretation; including the selection of images which would warrant the time and expense of quantitative analysis by computer or electronic methods.

If the analyst is to recognize information in the image, it must be reproduced in a way that permits visual identification. Unfortunately in some earth sciences, important information is characterized by very low spectral reflectance levels, or by low inherent contrast between the subject and its background, or both. There are also atmospheric effects which further complicate the situation. As a result, the remote sensor may be required to record this class of data on the threshold of its response curve.

In the Landsat system, which must serve a multitude of disciplines having very diverse requirements, it is not possible to have a single specification for image reproduction that will completely satisfy the whole gamut of user needs. Densities in the standard black-and-white (B/W) photographic image product are therefore carefully designed to represent the spectral reflectance values of the scene as closely as possible at the same contrast and brightness levels viewed by the sensor from its space platform. As a result, although the significant information may be faithfully reproduced in the photographic image, it can be close to, or below the threshold of visual interpretation.

There are several photographic methods of reprocessing and reprinting Landsat images in which such marginal information is greatly enhanced for visual interpretation, or even for analysis by video digitizing equipment.

Several of the methods perform operations such as contrast stretching, density slicing, and multispectral addition and subtraction, achieving results similar to those done with machine techniques of image processing, but in a simpler manner.

Additive-color viewing of multispectral imagery by projection is one of the most effective and rapid means of displaying Landsat images to the analyst, since image brightness and color hues may be changed to emphasize particular subjects, even while viewing. In additive-color viewing, the B/W positive Landsat multispectral transparencies are used to form the color display; by modifying these B/W transparencies, it is possible to very significantly enhance the color display and the detectibility of image information.

Consequently, much of what follows discusses ways to reprocess Landsat B/W transparencies. In some cases, the modified images would be used in additive projection, but in others it may be found that the reprocessed images have been improved sufficiently in quality to be valuable for interpretation in the B/W form, and at much larger scales.

Landsat coverage is often complemented by multispectral and color aerial photography taken at much larger scales. Such images also may be reprocessed to advantage by the same techniques. Many Landsat images have data that can be reduced to usable information, by visual interpretation of images enlarged at 1:500,000, 1:250,000, or even larger scales.

While the methods discussed are relatively simple, and use standard darkroom equipment and conventional materials, exact details of materials, exposure, processing times, etc., will differ with the types of equipment, facilities, and photographic materials available. Although certain proprietary brand names are mentioned, similar materials made by other manufacturers are likely to work just as well, and can be adapted to the procedures. Materials not mentioned may prove even more effective in some cases.

It is not only feasible, but well worthwhile for the user to establish his own facilities for reprocessing Landsat B/W images to suit the variety of his own specialized needs. Once the basic factors have been worked out, it is possible to set up a routine rapid and economic production flow for image reprocessing.

Some image characteristics

Every photointerpreter is familiar with the feeling that more information is buried in the image than he is able to see, or interpret with confidence and accuracy. He is often right.

Characteristics of subjects in the image which the interpreter uses for analysis are: size, shape, pattern, texture, shadow, color, and tone. In photographic terms, the most important of these is tone. Variation in the tone (or density scale, as it is more accurately named) is the common factor which permits visualization of all other image characteristics. Only the two-dimensional spatial arrangements of density variation make possible the perception of size, shape, edges, pattern, texture, and shadow. Multispectral imaging has added the color dimension, where density variation are related to spectral reflectances. Density (or color) variations thus define all the resolvable detail in the image.

In many earth-resources subjects, image information is often associated with very small differences in tone, or density gradient or spectral change, which makes difficult or impossible the visual identification of object boundaries. Recognition of such subtle changes in density gradient becomes even more important in multispectral imagery, as representing the very slight changes in spectral reflectances which can provide positive clues for subject identification. But even when the set of images is displayed in additive color, density differences in a particular subject, between spectral bands, still may be too small to permit separating the subject from the background by its color coding.

The problem in B/W or color is a lack of visual contrast. Most image-enhancement processes involve modifying image densities and contrast for improving visual detection of information. Contrast is the key element, and it must be of an order which allows perception.

Atmospheric haze effects and image contrast.--Quite apart from low inherent contrast in natural subjects, there is a more serious cause of contrast degradation in the image: atmospheric haze. It is well known that sunlight incident on the scene is scattered into a luminous haze, which rises in intensity as shorter wavelengths are approached. Aerosols--dust, pollen, moisture droplets, industrial pollutants, salt nucleii--are the main scattering agents, creating atmospheric hazes that vary with sun angle, season, and the type, concentration, and mixture of aerosols. The intensity of haze effects is seldom predictable, but can reach luminosities as high as 500-700 foot lamberts. The MSS-4 green band (500-600 nm) is the most affected by atmospheric haze (and the 450-500 nm band proposed for the Thematic Mapping Satellite will be even more sensitive). Haze effects can occur even in the MSS-5 and MSS-6 red and near-infrared (IR) bands, but seldom intrude on MSS-7.

Sensors viewing the earth through haze-light in the green and blue spectral regions can only detect reflectances from the scene which have radiances higher than that of the haze. Also, because haze-light forms a larger proportion of the image light reflected from subjects of low radiance than it does from those of high radiance, a nonlinear distortion is introduced into the contrast of the scene as recorded by the space sensor.

Many subjects in nature and, curiously enough, green vegetation, are not strongly reflective in the 500-600 nm MSS-4 green band. In the case of vegetation, quite different species may have rather small differences in reflectivity in this region, and have low contrast between one another. This makes it difficult to detect such differences, even under the best imaging conditions. The low image contrast usually found in the MSS-4 band affects visual ability to detect and recognize many subjects. For these reasons, some workers have felt that useful information is seldom found in the MSS-4 band. However, it has been shown that by reprocessing MSS-4 imagery at higher gammas, significant improvements often can be made in restoring much data for visual detectability.

As a footnote, high-contrast (high gamma) color separations in the blue and green spectral regions, made from Gemini, Apollo, and Skylab natural color photographs, confirm that with judicious control over gamma, information invaluable to many disciplines is recorded in these spectral regions, and can be reproduced for visual interpretation and additive-color work.

It should be clear, having gone this far, that increasing or manipulating the contrast of data already present in normal Landsat imagery is a powerful means of raising such data to levels where it can be recognized by visual interpretation, and can be converted from data to useful information.

Density, gamma, and contrast.--Photographic density (D) is defined as $\log_{10}$ opacity; the latter is the reciprocal of transmittance, or the ratio of light transmitted through the silver image to that incident upon it:

$$D = \log_{10} \text{opacity} = \log_{10} \frac{\text{incident}}{\text{transmitted}}$$

A density value can be considered as a measure of the amount of silver developed in the film, as a result of exposure (E) to radiation. The characteristic response of a film is measured by plotting the densities resulting from a series of known, increasing exposure levels. The gradient, or slope-angle of the density-exposure curve, is expressed numerically as gamma (γ). This number is derived by comparing density-exposure relationships as follows:

$$\gamma = \frac{(D_2 - D_1)}{(\log_{10} E_2 - \log_{10} E_1)}$$

Where the D (which is a log number) and $\log_{10}E$ plotting coordinates are on the same scale, gamma is equal to the tangent of the angle formed between the baseline and that part of the response curve being measured. The relationship between density, gamma, and exposure are shown in figure 1.

Simple ways of determining gamma adequate for manual process control, are discussed elsewhere in this paper.

Gamma and contrast are often used as interchangeable terms for describing an image characteristic; but gamma is a measurable value, whereas the assessment of "contrast" is highly subjective and varies among observers. Low, medium and high contrast films do have low, medium, and high gamma response curves, but the subjects recorded on them may be in any order of inherent contrast. A low-contrast subject recorded on a high-contrast film will have a higher apparent scene contrast than was viewed from the sensor position.

As seen in figure 1, exposures which result in densities falling on the straight line part of the film response curve are in a 1:1 D/E relationship. That is, the scene reflectance range (represented by the $\log_{10}E$ range) can be equated with the density range on a 1:1 basis. As a result, the scene will be recorded exactly with its own inherent contrast range, whether this is low or high. Standard Landsat imagery is designed to reproduce the scene at γ 1.0, exactly as viewed from the space stations: the subject contrast as seen by the sensor, and the true contrast may be quite different.

In figure 1 a γ2.0 film response curve is also given. In this case, the density-exposure range ratio is 2:1; the contrast of the scene will be amplified in the image by a factor of 2x. At gammas less than 1.0, the recorded scene contrast would be lessened.

In photographic image-enhancement processes gammas from 1.0 to over 6.0 may be employed. As gamma is increased, so the density range increases. This shortens the exposure range which will allow the printing of image densities usable for visual analysis. In reprocessing Landsat

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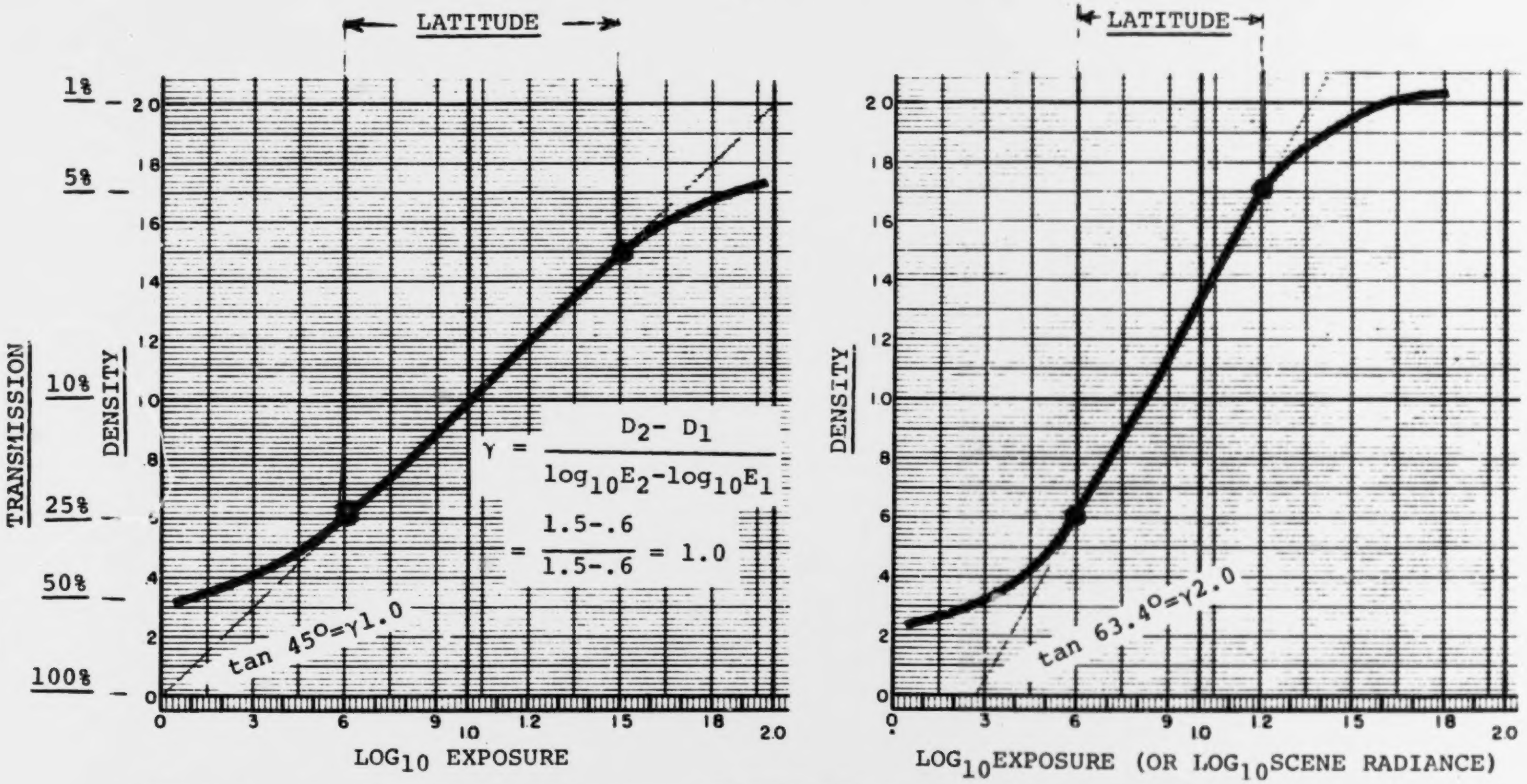

FIGURE 1. DENSITY, GAMMA & EXPOSURE RELATIONSHIPS. At γ1.0, scene brightnesses (equivalent to $\log_{10}E$) recorded on the straight part of the response curve are reproduced as densities, where $\Delta\log_{10}E = \Delta D$; i.e. the scene reproduced at the same contrast ratios as viewed by the sensor. At γ2.0, $\Delta\log_{10}E = 2(\Delta D)$; the apparent contrast of the scene is amplified by a factor of 2. These are negative curves. When negatives are printed to positives, densities in the negative form the new exposure scale.

In response curves of positive images, the toes and shoulders therefore curve in the opposite directions, and the gradient slope-angle is rotated 180°.

With increasing gamma, the exposure latitude for straight line recording is reduced accordingly.

These curves are for illustration only, and do not represent the response of real films; which may have either better or less useful response for reproducing images. As an exercise, construct the straight line response of a lithographic film on one of the above at γ=6.0 (at an angle of 80.5° from the baseline). Note how the latitude of exposure becomes extremely restricted, but the density difference ($\log_{10}$ Exposure Scale) becomes amplified by a factor of 6 over γ1.0.

images, either by contact or enlargement printing, densities in the image to be enhanced provide the exposure range for the reproduction material; the original range of image densities modulates the new exposure. Depending on the scene and its subject matter--which may occupy much of the 2.0 density range limit specified for Landsat imagery--it may not be possible to reproduce at high gammas all the data in the scene. The reproduction material may have too short an exposure latitude to permit this.

There are certain subjects where high gammas and short exposure latitudes are encountered during reproduction; among them, ocean and water subjects, snow, or cloud. That is, the lower or higher than other scene densities. As an example, bottom reflectances from shallow waters may be enhanced significantly by reprinting on lithographic materials, at gammas about 7.0 or 8.0. In this case, the densities of adjacent terrain information may fail completely to be reproduced. Similarly, in reprocessing images of snow cover, the discrimination between new and old snow may be made possible only at the expense of losing other, non-snow-related data in the scene. These are special cases, but by no means unique, for which each organization will have to develop its own image enhancement techniques and priorities, according to the importance it assigns to different subjects.

Reproduction gamma.--Since an objective is to increase the contrast of spatial data in the image for improving visual detectability, introducing the concept of reproduction gamma is appropriate here. Reproduction gamma is the product of all the gamma, or contrast changes the image has undergone during its reproduction cycle. Assuming that Landsat input working images have been produced at the standard $\gamma 1.0$, if a $\gamma 1.5$ negative is made from the input, followed by a positive $\gamma 2.0$ print made from it, the new positive, the final product, will have a reproduction gamma of 3.0 (1.0 x 1.5 x 2.0); and scene contrasts will be amplified by a factor of 3x. In a specific case, an 0.02 D difference between a subject and its background may not be visually recognized in the input image; but in the $\gamma 3.0$ print, the density difference is now 0.06 D, three times greater, and becomes more readily detectible.

Contrast stretching

The most simple, economical, and effective of image reprocessing methods is contrast stretching by means of photographic materials. The objective is to raise the contrast of particular subjects to a degree which will separate them from their backgrounds, making them visually identifiable.

In MSS-4 imagery, the subjects may have reflectance levels barely above that of the haze; that is, barely above the quantization noise level in the sensor (at normal gain setting). When contrast is enhanced, both the luminance of the subject and that noise originating in the sensor will be increased, which affects the ability to resolve detail. This is not always important. For example, when enhancing water-bottom reflectances in an MSS-4 image, where clear water penetration is best, the fact that an area of bottom reflectance can be detected may be more important than to be able to resolve detail, as it indicates shallow water.

Where highly reflective subjects (such as in the discrimination between new and old snow) are to have the contrast stretched, the granular* appearance of sensor quantization noise in the image is generally not a serious problem.

In reprocessing Landsat images, it is preferable to work as closely to the original film record printed by the Electron Beam Recorder (EBR) as possible. Both the 70-mm and 240-mm positive image sizes available to the analyst are generally of the third generation. Positive working images are therefore desirable, in either size, for preparing new imagery.

If the 70-mm working image is to be used for additive-color viewing, it can be contact printed at higher gamma, preferably in vacuum printing equipment to ensure minimum loss of detail. If it is to be enlarged to another scale, only a well-made and efficient condenser enlarger, with high-resolution lenses designed for enlarging should be used.

In the case of direct contact printing, several options are available. The input (working positive) image may be printed from a positive to a negative on a high-resolution film such as Eastman Kokak (EK) Fine Grain Aerial Duplicating 2430, 4 mil base, or EK Aerographic Duplicating Film 4421 (thick base). The former is machine processable, but the latter is best dealt with by manual, tray processing. Both films have extremely high resolution, and little loss of detail should be encountered with efficient contact printing equipment. Both films are also capable of producing gammas of 1.0-1.5.

When a negative is made, exposure should be sufficient to ensure that the lowest densities of the input image are reproduced on the negative film on its straight line region. These may be in the 2.5-2.9 density region, according to the type of reproduction film and developer used.

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* Granularity, as a term, is more properly applied to the structure of the developed image, as a characteristic of the film emulsion. The films used for reproducing standard Landsat imagery do not have granular effects which are likely to influence image quality, except at very high degrees of enlargement.

An example of an MSS-4 image which has been reprocessed at higher gamma is shown in figure 2.

When the negative is made from the input image, several options are now open. The negative may be enlarged to some pre-selected scale, with further control over the gamma of reproduction. If the same $\gamma 1.5$ film materials (such as 2430 film) are used for the enlarged image, reproduction gammas of over 2.0 can be produced. Or other films can be utilized, to achieve much higher gammas according to the nature of the subject, the needs of individual disciplines, and the kind of image display planned for the re-processed imagery. Display may vary from use for conventional B/W interpretation, diazo color foil reproduction, additive-color display, or color film or paper printing. For the interpreter interested only in subjects which originally have very short tone (density) ranges, extremely high negatives or positives show only the critical subject matter with the original density range greatly increased at the expense of other information in the image. Discrimination of ocean bottom reflectances, or snow, or cloud detail, or differences in green vegetation reflectances, are subjects which have been mentioned and which may benefit from high gamma reproduction.

The extremely high gamma films are found among the lithographic and line-copy materials used in the graphic arts field. For example, EK Kodalith Ortho Film 2556 Type 3 (Estar Base) will produce gammas above 8.0-9.0, when developed as recommended. Emulsions in this class are made by several manufacturers and are usually designed to work with special developers which promote in situ infectious development from the byproducts of initial development. Once a minimal amount of silver has been reduced in the exposed halide grain, the remainder of the grain is fully converted to silver by the developer, whether or not it has received sufficient exposure to cause this reaction normally.

However, high-sulfite developers, such as Kodak D-19, tend to inhibit infectious development, and serve to restrain gammas to the 6.0 to 8.0 range. Employing such high gammas is not uncommon in printing positive images, where the problem is to enhance very low contrast subject information.

Very high gamma reproduction is usually confined to the MSS-4 Landsat band, but may be used in any spectral region, where it is necessary to separate very small scene reflectance changes, as represented by densities in the film; as a case in point, separating subtle differences in infrared reflectivity from vegetation in the MSS-7 near infrared band.

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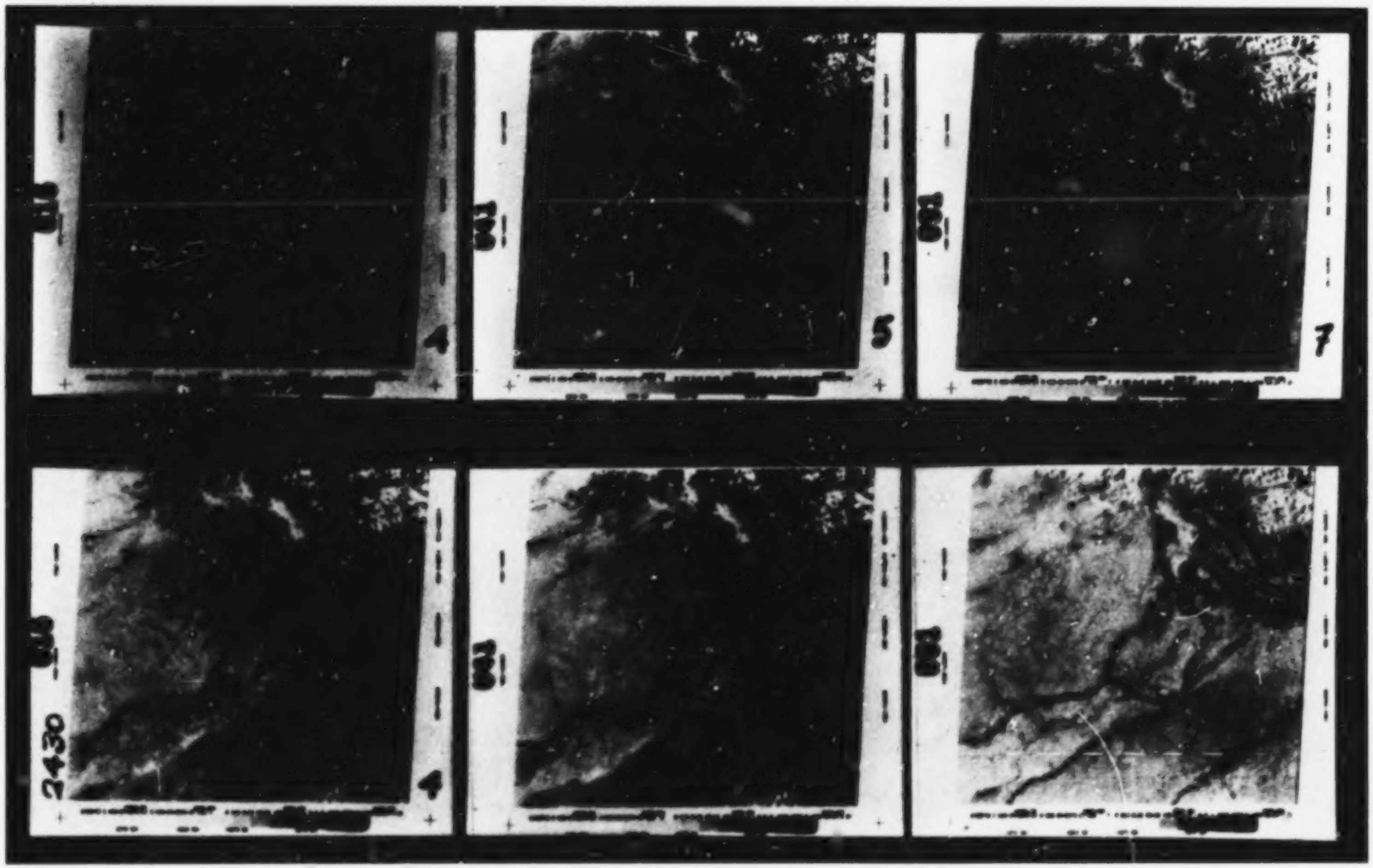

FIGURE 2. Top row, MSS bands 4, 5, and 7 (green, red and infrared) reproduced at γ1.0 at standard contrast values as received from the reproduction center. Bottom row: the same 70 mm images reprinted at higher gammas on Kodak 2430 Fine Grain Aerial Duplicating Film. The original positive images were contact printed on 2430 film to make negatives; which were then contact printed, again on 2430 film to produce the higher contrast positives. By varying development times in the negative and positive printings the individual gammas of the new positives were controlled: MSS-4, γ3.5; MSS-5, γ2.0 and MSS-7, γ1.70. Notice the improved reproduction of data in MSS-4 (ERTS E-1046-05124, 7 Sep 72, Pakistan).

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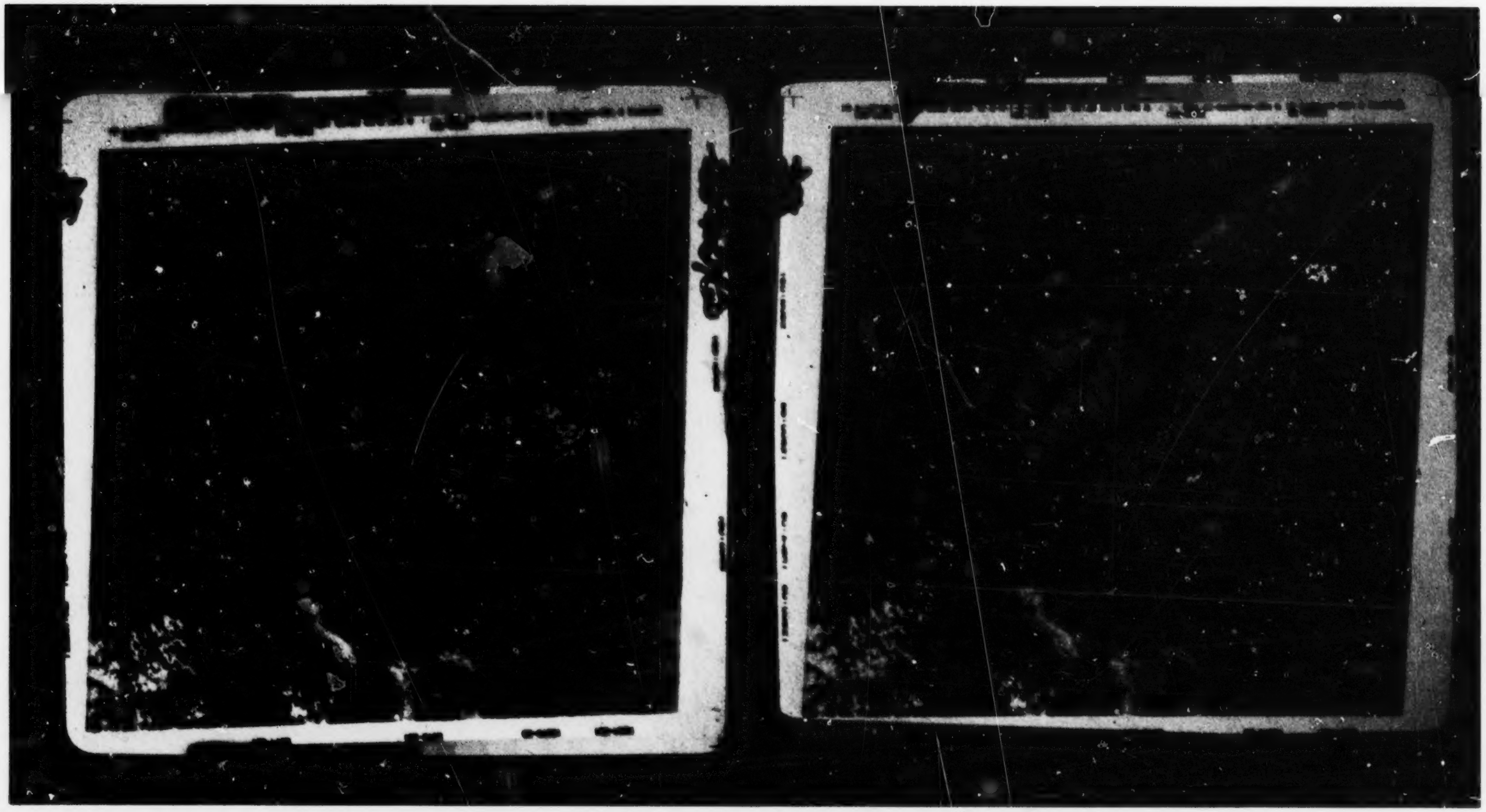

FIGURE 2A. Left - From a Kodachrome of the additive color image projected on the screen of an I^2S viewer, using the standard, normal contrast 70 mm images of MSS-4, -5 and -7, shown in the top row, Figure 2. Right - similar photograph of the same bands using the 70 mm higher contrast images shown in the bottom row. The better color saturation in the right image significantly increases visual interpretability. The same filter combinations (blue, green, red) were used in each case. (Pakistan, E-1046-05124, 7 Sep 72)

Many needs of the interpreter often can be met by positive transparencies which have gammas in the 3.0 to 5.0 range; many film emulsions are available for satisfying this requirement. By using different types of developer, a wide range of gamma control can be exercised. Two types which have been found useful, and which have long straight-line, linear reproduction characteristics, are EK Separation Negative Film 4133, Type 2, and EK Contrast Process Ortho or Pan Films, 4154, and 4155 respectively. The 4155 panchromatic film is only necessary when color-separating natural and false color IR films; the 4154 ortho emulsion is generally used for B/W reproduction of Landsat images, since it can be worked with under red safelight illumination. These films all have very fine grain and high resolution for reproducing with minimal loss, either by contact or enlargement, the information in Landsat imagery. Also, their gamma response characteristics may be controlled closely, with a number of developer types, such as EK D-19, D-11, and HC-110. (Other manufacturers have very similar formulae, either in packaged form, or with published directions for making the solutions.)

Assuming that negatives made from the input, working positive Landsat images have been processed to γ1.5, it will be seen that the contact or enlarged positives made on the emulsions named above or their equivalents can be processed to 3.0-5.0 gamma.

The reproduction gammas of the positives will then be in the 4.5 to 7.5 gamma ranges, according to the material and developer chosen.

Contrast stretching with direct reversal materials

Several manufacturers make direct reversal materials, by which a positive is reproduced as a positive image by normal exposure and a single development. EK has two emulsions of interest in this category: Aerographic Direct Duplicating Film 2422, which processes in D-19 to an average gamma of 1.4; and High Speed Duplicating Film 2575 (and 4574, Estar, Thick Base). The latter reaches γ5.7 with Kodalith Super RT developer. Both emulsions have extremely fine grain and high resolution. One of the images in figure 2 was printed from the MSS-4 70-mm, directly on 2575.

Another direct reversal film is EK Kodalith MP High Speed Duplicating Film 2565 (and 4565 Estar, Thick Base). This film is designed for machine processing; it reaches γ11.0 plus, with Kodalith MP developer.

Photographic masking

In this technique, a positive and a negative image of the scene are registered together image-wise* and a new image, the mask, is printed from the combination, at some pre-selected density and gamma. The mask may be either positive or negative, and will add to, or subtract from the density range of the image being masked . It will be seen that the density and gamma of the mask are most significant in producing the desired density and contrast modifications in the new image.

With Landsat and other multispectral imagery, a negative mask is usally made from a different spectral record than the positive image being masked. This provides the equivalent to spectral band subtraction in computer image processing. Different spectral bands also may be added together by combining two images of the same sign; positive, or negative.

Unlike the digital computer, pivel by pivel, process in photo-image processing, all elements of the continuous-tone density scales of the two images are processed simultaneously over the whole image areas. To avoid spurious results, selection of the type of photosensitive material for the mask, and its exposure and processing, must be done with care.

There are numerous possible applications for photographic image masking for modifying and enhancing images of earth resources subjects. For spectral band subtraction, it is usual to work with the 240 mm, 1:1,000,000 scale input positives; which are assumed to have been processed to $\gamma 1.0$. A negative is printed from the spectral band which is to be subtracted from the chosen band, exposure being controlled to give the necessary density range when the film is processed to $\gamma 1.0$. When the $\gamma 1.0$ mask is registered with the image to be masked, the individual steps in the gray scale printed on the images should disappear, and the whole strip will appear to have a uniform density. This condition usually can be seen quite easily; or the opposite density steps can be measured with a densitometer. When added together, each pair of pos-neg steps should have a density value about the same as its neighbors. In practice, this may be difficult to achieve at one or the other end of the gray scale, since there may have been small differences in the gray scales of the input images.

To achieve as exact a match as possible, the masking film must have a long, straight-line portion, within the 0.4-2.4 density range normal to Landsat standard transparencies. Kodak Gravure Positive Film, 4135, processed in D-11 developer can meet this requirement.

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* To ensure rapid and accurate registration of images, a registration punch and register pins are needed. The image to be printed is punched, and the printed material is punched and registered, on pins, to the former before exposure.

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The effect of a well-matched spectral mask is to cancel all reflectances in the two spectral images which have the same order of radiance, with only the differences printing out in the new image. To satisfy this condition, it is usually necessary to find the correct time of exposure for the mask by trial and error, because of variations in atmospheric conditions.

Masking, employing images taken in the same spectral band at different dates, can be useful in revealing changes of conditions that have taken place in the interim. The new image must be interpreted with caution, since different sun elevations, shadows, and atmospheric conditions are likely to be present between the two. This application is most successful with agricultural subjects, using MSS-6 or -7 images, in which atmospheric effects are minimal. Furthermore, because many crops are situated on land having little relief, shadows seldom interfere.

Masking of images of water bodies has been found useful in reducing surface effects which tend to confuse analysis. Reflections from large patches of wind-generated waves are common in Landsat images, and can be mistaken for reflections from bottoms. If present, such reflections will be found in all four MSS bands, and clearly so in MSS-7 which records little or nothing below the surface of even shallow water. While some sediments on, or close to the surface may also be recorded in all four bands, sediments usually can be distinguished from rough surface water by the more detailed and ordered patterns they take. While water surface masks are usually made from the MSS-7 image, there are cases where MSS-5 and -6 masks will serve. The negative of water surface reflectances is made by employing an exposure which is just sufficient to cancel their appearance in the positive from which it is made. Processing is, of course, to γ 1.0. To confirm cancellation, it may be necessary to view the positive with its registered mask by intense rear-illumination, since the MSS-7 image of water is usually quite dense.

When a water mask is registered image-wise with the MSS-4 positive, a new image is printed. If the mask has been made properly, the surface effects will be reduced or substantially removed from the new image, aiding its interpretation. It is not possible, of course, to restore subsurface information which was hidden by the surface effects.

Water surface masks have also been used to reduce the effects of waves in multispectral images exposed with aircraft cameras; and in aerial color images, where the mask is prepared from a red separation negative of the scene. The mask is registered with the color image, and is followed by further color separation with blue or green filters to secure subsurface information present in those spectral regions.

Figure 3 shows a case where it was desired to mask out very thin, wispy clouds, which hindered the assessment of areas of shallow ocean water. For this purpose, the mask was made from the MSS-5 (red) image, as the thin cloud had insufficient density in either of the two infrared bands to be usable for mask preparation. The mask was registered with the MSS-4 image, and the result is given in figure 4.

In another application, a mask was used to reduce non-uniform, repetitive errors in images acquired with Landsat-1 Return Beam Vidicons (RBVs). A radiometric correction program had been developed by NASA to reduce shading errors during post-acquisition signal processing, based on an 18 x 18 matrix of point measurements made of the vidicon plate photo-response during calibration. Data from the 364 points determined corrections to be made in image generation. However, the number of correction points appeared to be too limited for smoothing some major shading errors between the points. As a result the same errors occurred in the same place in each scene. Some local deviations in image density were much larger than the maximum 10 percent error permitted by the correction program.

To prepare the mask, a relatively cloud free, 1:1,000,000-scale RBV-1 positive transparency which depicted a uniformly reflecting ocean surface was found; the scene included the repetitive residual errors found in other RBV-1 images. A $\gamma 1.0$ negative mask was made from the ocean image, with a maximum density of 0.60 D. It was then registered with the RBV-1 1:1,000,000-scale image it was desired to correct, and a new image was made from the combination. The results are shown in figure 5. The mask was made on Kodak Commercial Film, 4127 (Estar Thick Base), processed in D-19 developer.

Although the materials and techniques for masking are quite simple and amenable to precision control, some applications may require meticulous attention in establishing effective working methods.

Density slicing

Photographic density slicing converts the analog, continuous-tone-image into one displaying a series of "digital" steps, each representing a separate, different increment of density, completely isolated from lesser or greater densities. It is also called equidensitometry or isodensity contouring. Agfa-Gevaert makes Contour Film, a special emulsion for this purpose. There are several chemical treatments and photo-optical emulsion effects which can be practiced to make density slices; but these usually are difficult to control systematically.

Very precise and narrow density slices can be made with conventional lithographic films and developers. Where the sensitometric characteristics of the input image such as the density and gamma ranges in Landsat images, are known with their relationship to the radiometric characteristics

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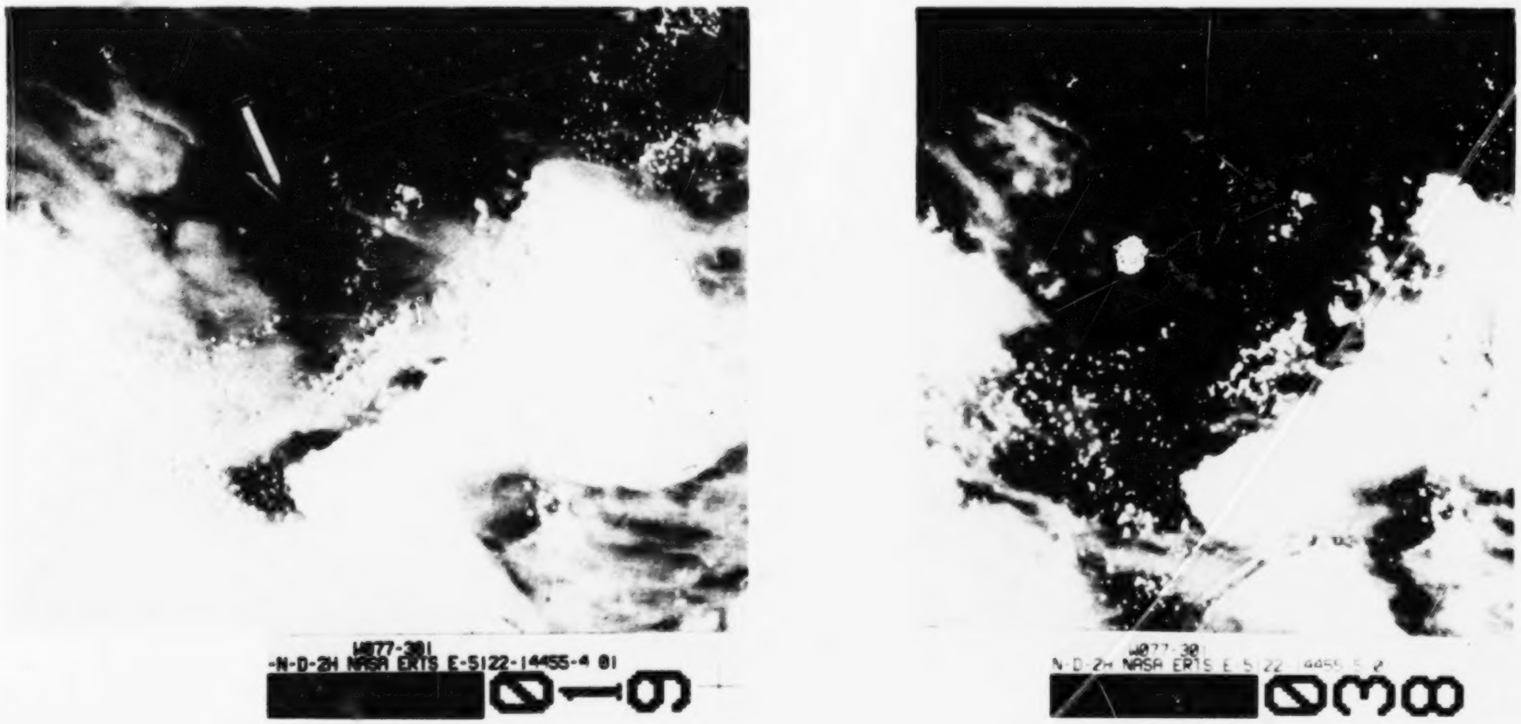
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FIGURE 3. The sections of MSS bands 4 and 5 shown above are of the Berry Islands region, in the Caribbean. MSS-4 (left) has been re-printed to reveal as well as possible the very faint reflections of light from the ocean bottom, indicated by the arrow. However, reflection from very light cloud in the area makes it impossible to discriminate between the cloud and the underwater shelf. Maximum clear water penetration is found in the green band MSS-4, but is much more limited in the red MSS-5 band as shown at the right. The clouds are similarly recorded in both MSS bands, and masking can be used to reduce their confusing effect on MSS-4, (Figure 4).

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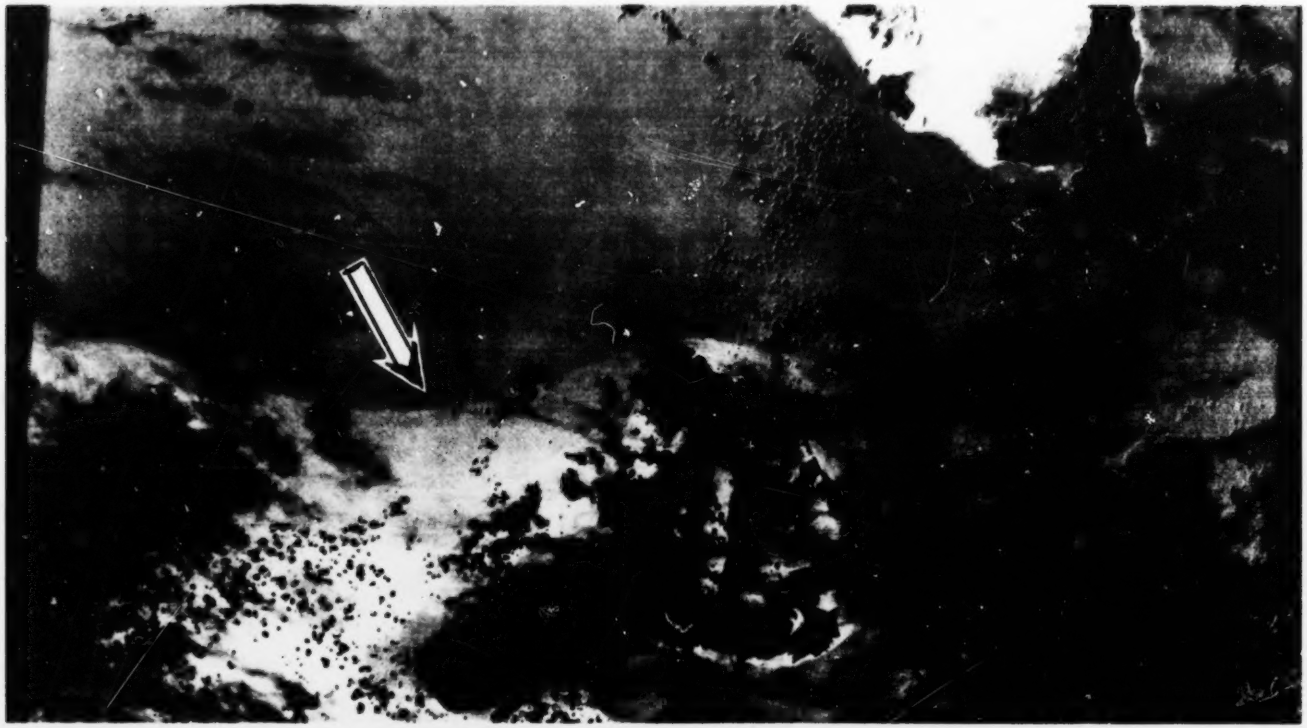

FIGURE 4. Example of photographic masking, to remove confusing or redundant information between two spectral bands. The MSS-4 and -5 images shown in Figure 3 both show light cloud over an area of ocean bottom, but only MSS-4 has underwater reflectance. A negative mask made from MSS-5 was exposed to produce cloud densities which just cancel those in the positive MSS-4 image. The negative mask (processed to $\gamma 1.0$) was registered with the MSS-4 positive, and a new negative was made from the combination. Above is the positive print made from the new negative, in which the areas and edges of the underwater shelves are clearly extracted from the overlying light cloud. Masked images often exhibit both positive and negative characteristics, as above, where dense clouds are black (negative) but the bottom reflectances are light (positive). The edge of the outer shelf is at a depth of about 20 fathoms (36.6 m).

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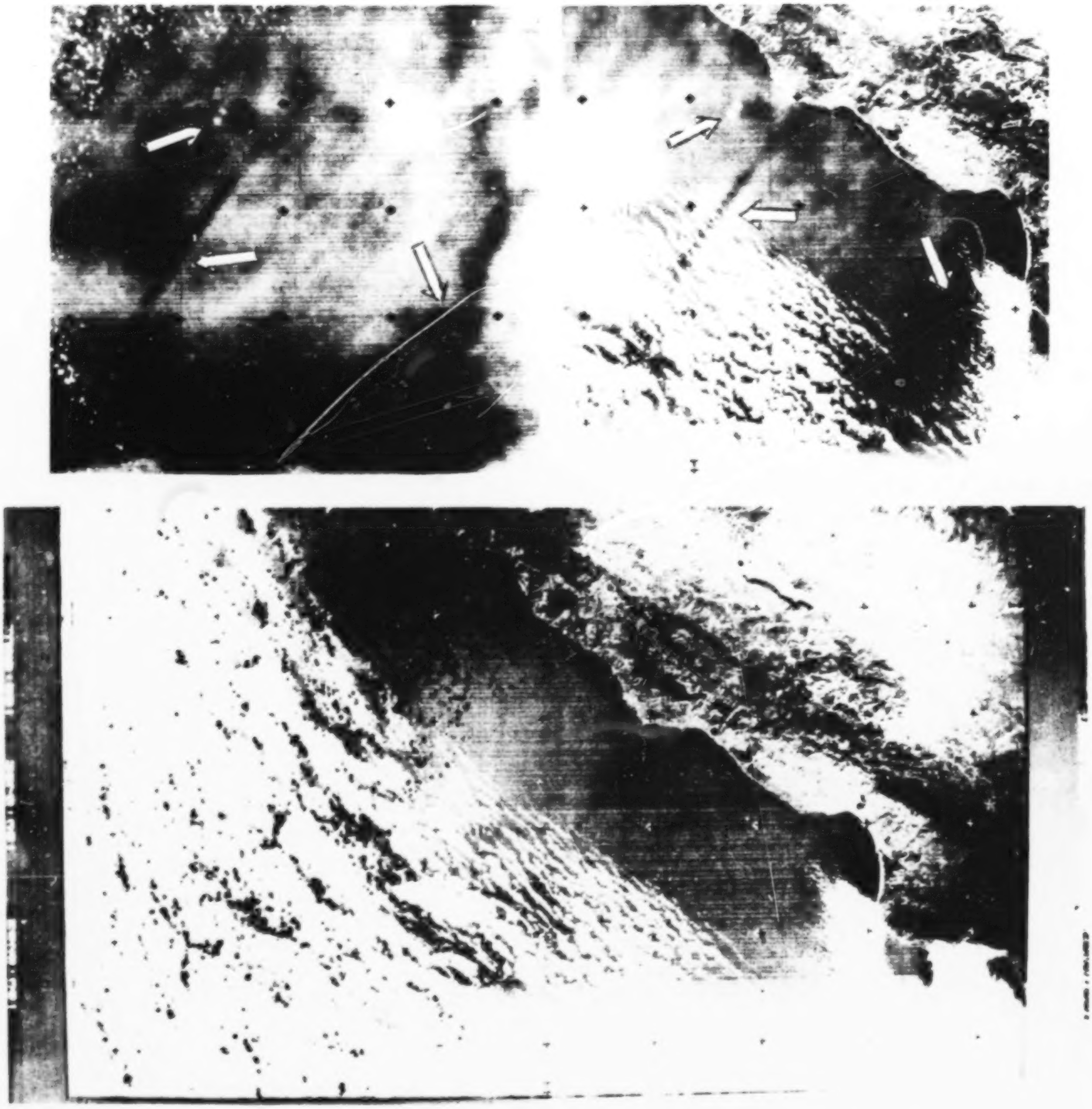

FIGURE 5. Repetitive residual shading errors remaining in ERTS RBV-1 band, after shading correction program, are shown above. Top left, open ocean which should be of a uniform density (E-1007-15160-1, 30 Jul 72). Top right, similar small section of E-1002-18140-1, 25 Jul 72. The patterns of uneven shading occur in both images, modifying apparent reflectances from land and water. The image shown at the bottom is corrected by masking (Page 186).

of the scene, density slices taken from the scene can be related to scene-radiance values--as recorded by the sensor. This also applies to aerial camera imagery, where the camera has been calibrated photometrically, and the sensitometry of the film is known.

Photographic density slicing already has wide usage in many industrial, medical, and scientific fields. Its applications in earth resources analysis are yet to be implemented on any large or routine scale; but much has already been done in aiding the interpretation of scenes significant in agriculture, forestry, water depth assessment, delineation of geological materials and structures, urban analysis, soil typing, vegetation speciation, and snow cover; there are even possible applications for relief shading in cartography under some circumstances where the density slicing of shadows on mountainsides creates the illusion of high relief. Density slicing also serves to isolate water bodies and streams from the terrain; but some editing of clouds and their shadows, and deep shadows in canyons may have to be accomplished by human intervention where these have the same density values as the water.

There are many ways to employ density slices for aiding the interpretation and display of information which will suggest themselves to the analyst. As an example, if one or more slices isolate certain features such as water, the slices can be registered with the continuous tone print of the scene, and a new image made, in which the density contours of the subject are removed, but their location with respect to other features in the continuous tone image now become apparent (fig. 6). Or density slices made from two or more spectral images of the same scene can be color coded and made into a composite image, which shows the relationship of the different spectral reflectances to each other.

Basic slicing technique

It has been noted that lithographic films (such as Kodak Ortho Film 2556) reach very high gammas when processed as recommended. Such films prove to be ideal for density slicing. The procedure is as follows:

A. The original input image, or an intermediate working image made from it at even higher gamma, is reprinted a number of times on lithographic film. Exposure is increased at each printing by a regular and predetermined increment; this may be done by doubling the previous exposure time; i.e., 4, 8, 16, 32, 64, seconds, etc.

The lith film will only record a very short range within the gray scale of the input film imagery. The range is limited at one end by underexposure, and image detail will be missing completely. Here, the film will be blank, and transparent. At the other end, overexposure (and infectious development) will produce extremely high densities with no detail. Somewhere near the toe of the film

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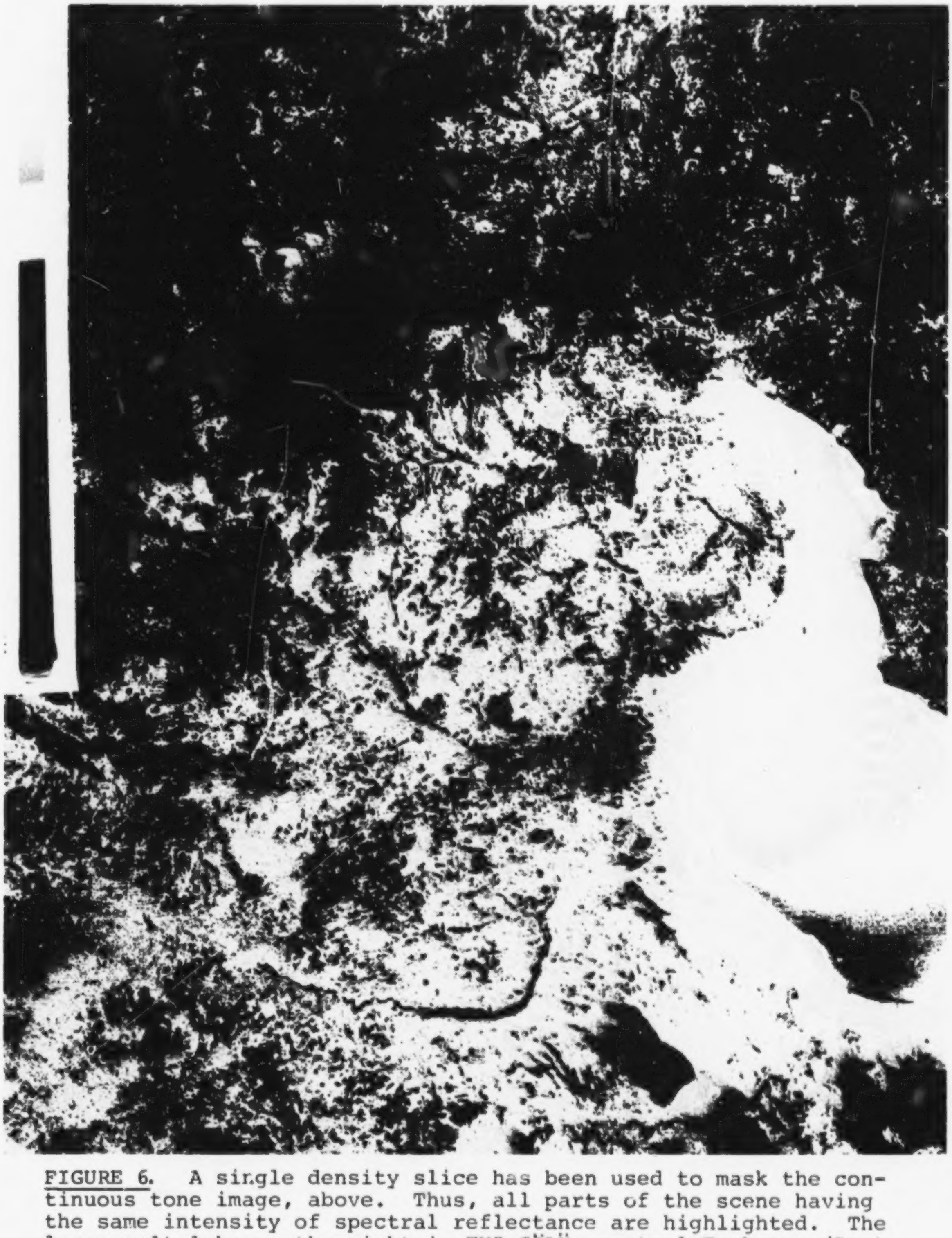

FIGURE 6. A single density slice has been used to mask the continuous tone image, above. Thus, all parts of the scene having the same intensity of spectral reflectance are highlighted. The large salt lake on the right is TUZ GÖLÜ, central Turkey. (Part of LANDSAT E-2179-07460-5, scale about 1:482,000.)

response curve, as shown in figure 7, a very short range of densities at less than maximum gamma will record a short density range of detail within the analog gray scale of the input image. Each of the "increments," the incremental exposures, will portray a slightly different, but adjacent portion of the original image gray scale.

B. Each of the increments in the exposure series is now reprinted, again on lith film, this time at a fixed exposure time. This produces images "complementary" to the films they were made from. These will be called "complements." (As the input image may be either positive or negative, the terms increment and complement will be used to avoid confusion.)

C. The complement made from the increment exposed at 8 seconds is then registered with the increment made at 4 seconds, as shown in figure 8. It will be seen that the overlapping toe regions of the two curves have a combined density which is much lower than all other densities in the increment and complement.

D. The combination complement-increment is then printed, again on lith film, at an exposure time adjusted to print through the low density region. This produces a density slice, as in figure 9.

E. Next, the complement made from the 16 seconds exposure is registered with the increment exposed at 8 seconds, to make a second density slice; and so on, through the series.

Where the larger orders of density difference occur in the gray scale of the input image, as at the edges of image detail, very narrow density contours (25 um - 0.001 inch or less) can be extracted. This kind of density slicing is capable of contouring density differences which are not perceptible to the eye. This will, in effect, increase apparent image resolution, and make more positive the identification of the shapes of spatial details.

Many features of importance in the earth resources sciences do not have sharply defined boundaries, e.g., the very gradual and slight changes in the spectral reflectance from soils, vegetation, and sediments in water. It may be difficult or impossible to determine visually where these changes occur in the B/W image; it can be done more readily with additive color display, but much more positively when density slicing is used.

With density slicing, it is possible to separate density changes as little as 0.01 D in the input image. However, this small a slice is in the order of random variation in the sensor, and in the reproduction cycle; and it is not recommended. The minimum slice usually should be confined to 0.03 D - 0.05 D, otherwise it may found that one is slicing random density variations among clumps of film grain, or even individual grains in very grainy emulsions.

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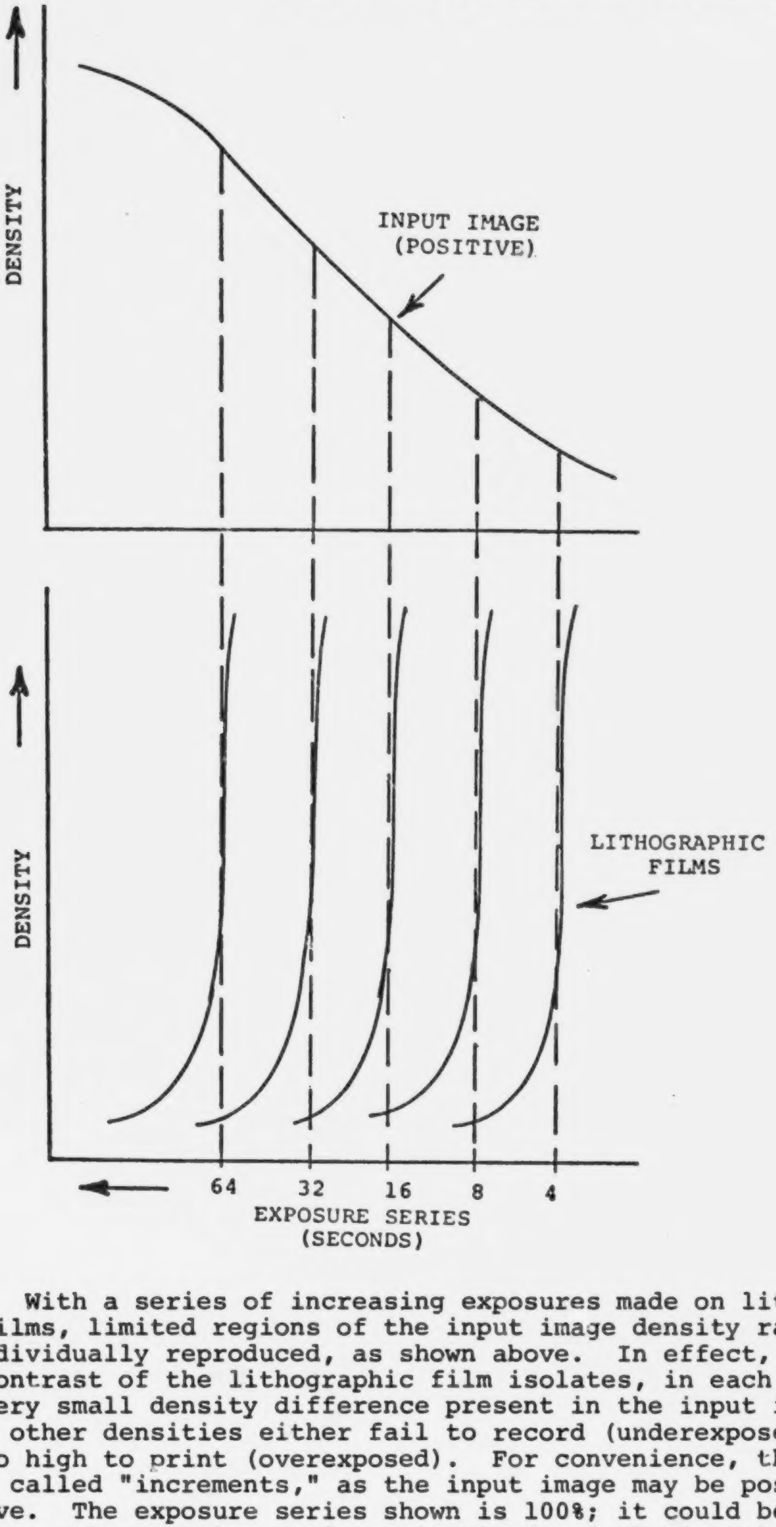

FIGURE 7. With a series of increasing exposures made on lithographic films, limited regions of the input image density range can be individually reproduced, as shown above. In effect, the extreme contrast of the lithographic film isolates, in each exposure, a very small density difference present in the input image, while all other densities either fail to record (underexposed) or become too high to print (overexposed). For convenience, these films are called "increments," as the input image may be positive or negative. The exposure series shown is 100%; it could be 50%, 200%, or any other regular series suitable for isolating the desired density differences from the input image.

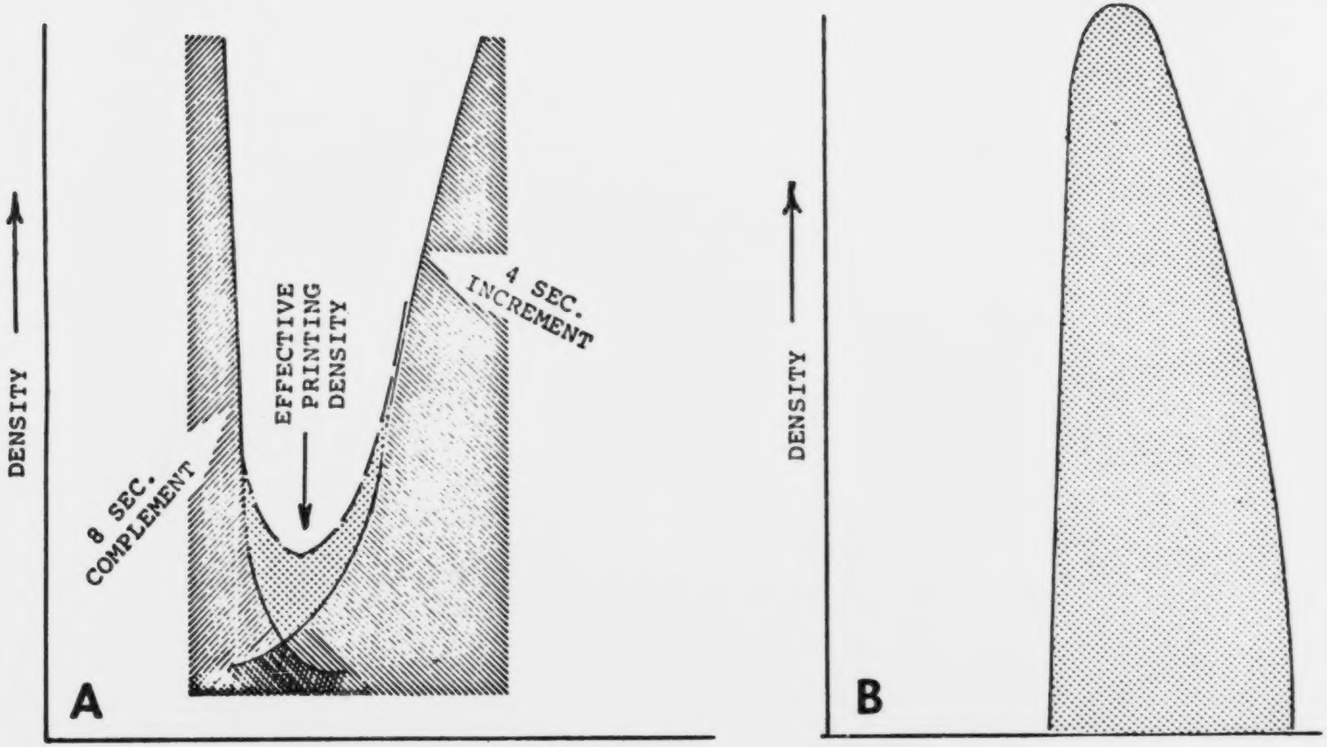

FIGURE 8. As explained in the text, the increments are each printed in registration, on lithographic film, to produce "complements." In the example above, the 4 second increment is registered with the 8 second complement, as shown at A. From this combination density slices can be printed, as in B, by several methods. Note that if the 4 sec increment had been combined with a 16 sec complement, a density slice would be formed, containing a larger density range from the input image. Similarly, if the incremental series had been based on 50% exposure increase, and the 4 sec increment had been combined with a 6 sec complement, a much shorter density range would be extracted.

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FIGURE 9. A single density slice is shown above and is printed from an increment-complement combination, as described on page 192. This was one of the slices made from the LANDSAT image of central Turkey shown in Figure 6. Even at the 1:480,000 image scale the density contours outlining the lake shore and river banks remain very narrow.

It was mentioned that the film emulsions on which Landsat images are printed normally do not offer granularity problems, relative to the spatial detail (or pixel dimensions) in the image. The images may be enlarged to the point where image information is no longer usefully conveyed without film granularity interfering. Because of the film quality, and under the right circumstances of scene subject matter and illumination, density slicing can be carried to the point where individual pixels are sliced from the image (figure 10).

Controlling density slice width

One of the problems in density slicing is to decide how narrow a slice is necessary for the best representation of the subject to be analyzed. Subjects may require broad or narrow slices made from the original scene, or a mixture of both. Density slicing is capable of enhancing and displaying information which the analyst did not realize the scene contained, it is often necessary to go through a trial-and-error series, until an optimum procedure is found.

The term "slice width" refers to the range of densities extracted by a single slice from the analog gray scale; this may be 0.05 D, or 0.30 D, or any range found to be useful. There are several ways to control slice width.

If, in the original series of increments, exposure had been increased only 50 percent each time, rather than 100 percent, i.e., instead of 4, 8, 16, 32, seconds, exposures of 4, 6, 9, 13.5, 20.2 seconds had been used, it is evident that a series of much narrower density ranges would be taken from the original gray scale. Or, if the 4 seconds increment had been combined with the 16 seconds complement rather than with the 8 seconds one, a doubling in density slice width would be obtained.

By these means, controlling the order of incremental exposure, and by assigning appropriate complements to be printed with the increments, predetermined slice widths can be made, and can be varied, through the image, according to the needs for analyzing the subject.

Varying slice width can be useful for more closely relating scene radiance values to the analog density range of the input image, particularly when these have been recorded on a non-linear part of the sensor response curve. This often occurs in aerial camera imagery, where certain subjects are recorded on the toe of the film curve. With the Landsat Multispectral Scanner, scene reflectances which are imaged at less than 20 percent of full sensor response are also recorded on the toe of the sensor response curve, which is non-linear. At 5 percent

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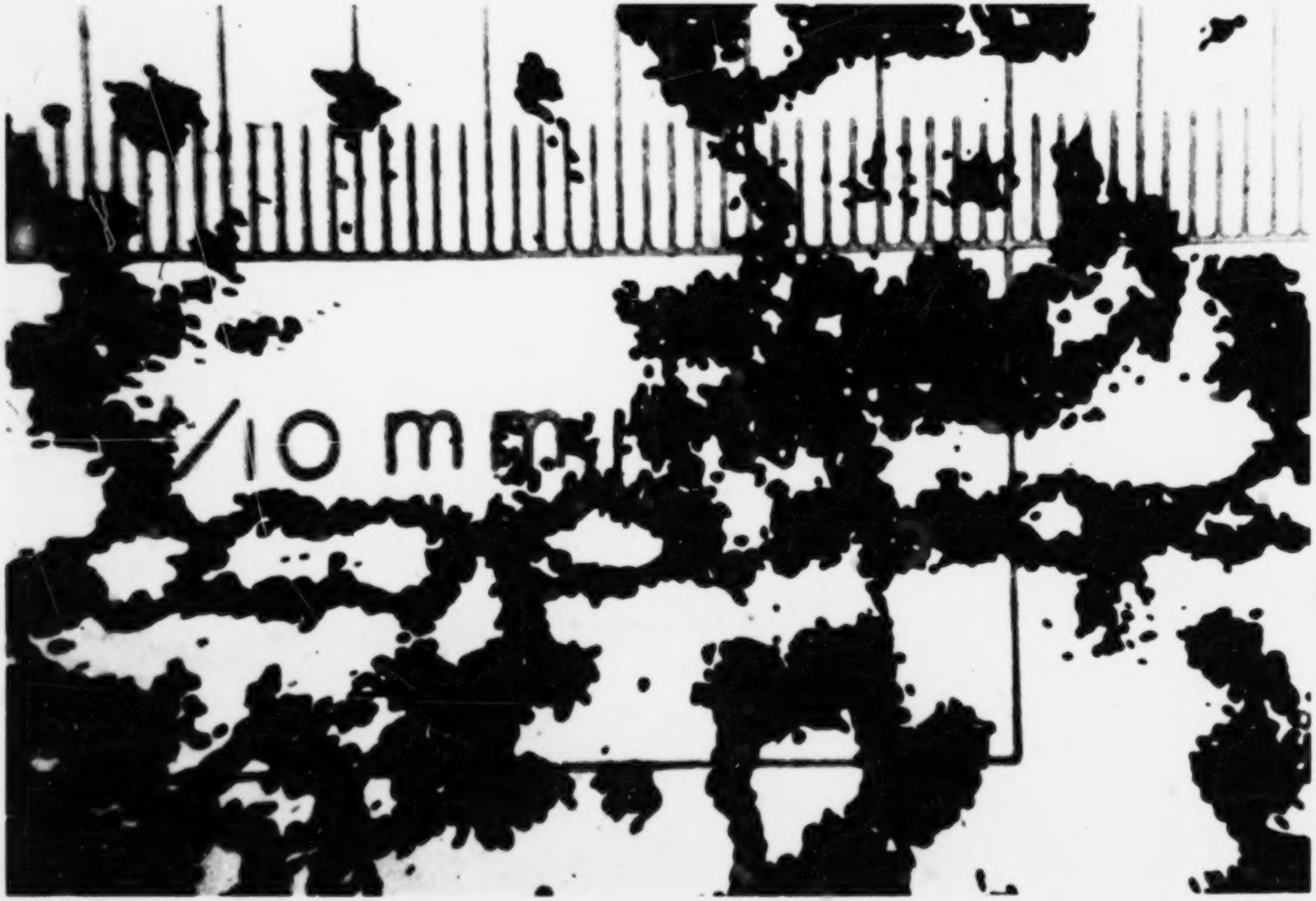

FIGURE 10. Density contours of consecutive individual pixels are outlined in the photomicrograph above, in the MSS scan line going from left to right, just below "1/10 MM." Also, similar density levels are sliced out of the central parts of other pixels, as in the three in the upper left. The density slice was made from a LANDSAT image enlarged to a scale of 1:286,000. The 1/10 MM graticule was placed on the density slice, and was photographed through a microscope.

response, the gradient is 0.85 (equivalent to gamma 0.85). This lowers scene contrast in the darker parts of the positive image.

Where narrow density slices are to be made from the normal Landsat image, it is best to contact print or to enlarge a section of the image at a suitable scale on a higher gamma film, such as an EK Contast Process Film (4154 or 4155). Enlargement is recommended, as the extra data revealed in a 1:250,000-scale image generally will be much improved over that in a 1:1,000-scale density slice. Otherwise, the potential power of density slicing will not be fully utilized. Density-sliced sections of Landsat imagery from a 70-mm film chip enlarged to a scale larger than 1:90,000 have shown an improved visual information content over those made at 1:250,000-scale for interpreting subsurface water data; and there are many similar conditions in other earth science subjects.

The purpose for reprinting Landsat imagery at a higher gamma is to increase the magnitude of density differences in the image gray scale. This will increase the margin of tolerances permissible in subsequent slicing operations, and will reduce effects of slight errors exposure times, or manual or machine processing steps. For example, if 0.05 D increments are to be made from the Landsat image, these can be extracted more easily from a print of the image in which 0.05 D differences have been increased to 0.20 D by reproduction at $\gamma 4.0$. The reprinted image then can be sliced at 0.20 D intervals without the stringent control which would be necessary when working on a $\gamma 1.0$ image. For instance, an 0.04 D error in slicing the $\gamma 4.0$ image would in reality be an error of only 0.01 D in the original image.

In the matter of control, however, it is essential to adhere to exact exposure times at constant voltage, and to process each film for the same time, at the same temperature. To ensure accurate and repeatable density slicing, it is necessary to set up and calibrate the facilities for doing this work; but this can be quite simple. To avoid human error, it is wise to use a repeatable, resettable, automatic timer for exposure.

It has been demonstrated that film exposed for density slicing can be processed successfully in automatic equipment designed for handling graphic arts materials. More precise control over slicing is likely to be gained, however, by tray processing. In doing this, the technician should carefully follow the manufacturer's recommendations on procedures for tray processing the emulsion used; the rate of agitation, time of development, temperature, draining, short stop, etc. Developers should be used only for their recommended lives, based on the cm^2 of emulsion processed.

It is necessary to have, somewhere in each increment and complement, a control gray scale which will not only identify the position and sign (+ or -) of individual films within the series, but which will also show the accuracy with which abutting slices have been made and their relation to the image gray scale. Step tablets may be used; they are available in 0.05, 0.10, 0.15, and 0.20 density units or even larger increments. Such step tablets are often made on rather coarse grained photo materials, which density slicing may sort out as grainy clumps of equal density in several adjacent steps; this makes it difficult to clearly identify which step is which.

Better control is to be gained with a continuous gray scale wedge, in which opacity is produced by almost grainless carbon particles,* and where density is a linear log function from one end to the other. An arbitrary number scale can be attached to the wedge, the whole being included at the edge of, or even in the image area of the film to be density sliced. With a gray scale of this kind, there is no question about where the increment, complement, or density slice begins or ends.

All that is needed for exposing the material is a pin-registration printing surface (preferably a vacuum printing frame for effective contact), and a point-source light 1.5 m - 2.0 m distant from it for exposing the film. The light should be rated at about 500 watts at full voltage. To avoid excessively long exposure times, voltage to the light can be controlled at a number of pre-determined settings, as follows:

> Starting at, say, 30 volts for the first exposure series, beginning at 4 seconds, and ending at 64 seconds; the next exposure time would be 128 seconds, and so on into very long times.
>
> To calibrate another lamp voltage which would permit the time sequence to begin again at 4 seconds, a 128-second exposure is made at 30 volts; then lamp voltage is increased to the point where a 4-second exposure time yields an increment equivalent to that produced by the 30 volt, 128-second exposure. The new voltage setting, which may be, say, 48 volts, permits the 4, 8, 16, etc., time series to continue to 64 seconds, whence a third voltage setting, again beginning at 4 seconds exposure time, can again be established.

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* A gray scale of this kind, made by Eastman Kodak, Rochester, New York, is identified as: Standard Rectangular Wedge, 15 x 2 cm M-type Carbon, laminated between acetate sheets.

Once the voltage settings have been determined, they can be returned to in furture operations without need for further calibration.

Lamp voltage may be controlled easily through a variable automatic transformer (Variac, Staco, etc.) or other economical device; but it is recommended that a good quality voltmeter be used, repeatable to ± 1 volt in the lower ranges.

Methods of displaying density-sliced images will be discussed later.

Displaying Enhanced Imagery in Color

The use of color in images of earth resources subjects has added a most useful dimension to the interpreter's ability to recognize and identify information. But with natural and false-color infrared films, the interpreter has little choice to alter colors in the image he is given, short of color separating and reprinting the material. The increasing use of additive color projection systems, however, gives the interpreter a much wider choice to color grass blue, rather than geen, or red, with the turn of a knob, and so the better to select color variations which pick out certain subjects.

It was noted earlier that reprocessing Landsat images to higher gammas provided greatly enhanced additive color displays where colors were brighter and more highly saturated. This improves the ability to see aras where small changes in spectral reflectances occur in the scene. It also helps the MSS-4 band to made useful contributions to the whole scene, which would not be possible in its normal, low-contrast rendition.

Often when the interpreter has balanced the additive color scene to suit his eye, and photographs the viewing screen with color film, the resulting color record is not what was intended. Color film emulsions work with limits fixed during manufacture, while the eye is highly adaptive to changes in color; in face, more than physical adaptation is involved. The brain, working with the visual impressions, tells the observer that he is "seeing" certain desired nuances of color. For example, a sheet of white paper is white in sunlight, and yellow in candlelight; but the viewer, seeing it by candlelight, sees it as white--because he "knows" it is white paper; whereas the daylight-balanced color film would record it as yellow. Tungsten illumination from the projection bulbs used in additive viewers is quite deficient in blue and green energy, compared with the yellow and red. It is usually better, therefore, to use color film balanced for artificial light when recording displays on an additive color screen,* since they are designed to enhance the shorter wavelength colors.

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* The red, green, and blue phosphors used in high-quality color television monitors are best recorded with colorfilms balanced for daylight. The grade of monitor supplied with eletronic density slicing equipment usually is of this kind.

If color negative films are used, some color balance corrections can be made when the negatives are printed to positives, if the user is able to influence the reproduction.

An enhancement of already enhanced additive color images, which may further emphasize image information not visible on the screen, sometimes may be made by recording it with Kodak Photomicrography Color Film 2483 (available in 4 x 5 inches and 36 exposure 35 mm). This is a very slow, high-color contrast, fine grain, natural color film.

Color transparencies to be viewed by transmitted light, or color prints to be displayed on white opaque backings for viewing by reflected light, may be made by contact printing two or more Landsat multispectral images onto the color material; Diazo Color foils offer a very simple process. The B/W positive MSS transparencies are exposed to the diazo material by an ultra-violet (UV) light source, producing a positive image directly, in the chosen color. Exposure to light destroys the diazo compound. The diazo transparency is processed by exposing it to ammonia vapor, which than couples chemically to form a dye in the unexposed areas. Contact exposure and processing can be carried out in machines used for office reproduction.

As the diazo color foils are available in the yellow, magenta, and cyan subtractive colors, prints made from three of the different MSS spectral images can be registered together to provide a false-color composite image. TECHNIFAX makes subtractive color foils for high contrast, as well as low-contrast reproduction; best color rendition is usually made with the high-contrast materials. For even higher color saturation, the MSS B/W positives to be printed can be reprocessed to higher gammas as recommended in another part of this paper. Diazo foils are also made in red, green, brown, and other colors, which sometimes can be of more help than a subtractive color composite in emphasizing certain subjects. Diazo foils are inexpensive, but may vary in color saturation, contrast, and printing speed, with age and from batch to batch. Fortunately, with most false-color earth resources imagery, an exact color reproduction is seldom necessary; the display will serve its purpose if the color differences are distinct and recognizable.

Display of density-sliced images

The display of density-sliced images can be by several methods. When the series of B/W density slices is pin-registered to form a composite image, the relationship of individual slices to the whole image and to each other becomes obscure. But if each slice is printed in a different color, the patterns which the density contours form become color-coded, and their position and significance are clarified. In forming a useful display, 6 to 12 or more contrasting colors may be necessary. 3-M NEGATIVE ACTING COLOR KEY materials have a good range of colors, with which the stronger of different colors can be given to a single slice by printing the slice twice in the same color, or in two different colors. The material is coated on a 2 mil polyester base which is thin enough to permit using a double thickness for one density slice. Light transmission through the composite becomes a problem after 10 or 12 slices.

As with diazo, the 3-M Color Key material is exposed by UV light. Since pin-registration is essential, a flat-bed printer must be used. The UV exposure hardens the color coating, and the unexposed part is rubbed off with an alcoholic "developer" solution and a cotton swab, to form the positive image. Very high line resolution can be obtained.

As this material is negative acting, the density slice may be printed directly on it from the combined increment-complement; otherwise, the density slices can be reprinted to positive form (clear contour lines), from which the Color Key prints are made. For the production printing of Color Key composites from the same scene, it is sometimes more convenient to print the color slices, each from a single sheet of film, rather than from the increment-complement combination. If there is no application for the density slices in their B/W form, the increment-complement combinations may be printed on a high-contrast direct reversal film, for printing on Color Key or other negative-acting color materials. Kodak 2575 High Speed Duplicating Film is suitable for this.

If the Color Key composite image is arranged with the colors in the order of scene reflectance, i.e., with the highest reflectance on top, and the lowest on the bottom, the composite, when placed in an illuminator, can be photographed in color from exaggerated stereo right and left positions. For greater exaggeration, transparent spacers may be inserted between the color slides. When viewed in stereo, the result is a color-coded relief image of relative scene reflectances. Probably the most useful application for this kind of display is in training, but it could be of assistance in interpretation, if the image consists of many colors.

In many applications, it is useful to the interpreter to have the individual density slices on separate sheets of B/W film, or in color; these can be removed from the composite image as single contours or in groups which illustrate particular subjects. There are other occasions when it is more satisfactory to reproduce the whole composite image in color on a simgle print or transparency. There are several ways of taking advantage of these options.

Cibachrome is a photographic material for reproducing multispectral and density-sliced images in color. It is positive-to-positive, and is available in white opaque base and in transparency form. Additive color viewers of the type made by International Imaging Systems (I^2S) have accessories which enable the additive color image displayed on the viewing screen to be recorded with Cibachrome. An advantage of this material is its rapid three-bath processing procedure. Both the emulsions provided for the amateur and those for professional machine processing can be developed with simple tube equipment in 15 minutes or less.

Cibachrome is a bleach-out, subtractive, color emulsion; that is, exposure to red light bleaches out, or makes inactive the dyes which form other colors, leaving only the red. By explosing three Landsat MSS images in sequence through blue, green, and red filters, false color will be obtained in the print. This may be done by contact printing, and by use of an additive viewer, at the 1:1,000,000 or larger scales. This process can be as simple as using the uniform illumination from an enlarger with standard color separation filters as the exposing source, while a glass plate over the MSS positive and the Cibachrome should ensure adequate contact. Here again, however, it is recommended that the MSS positive images be reproduced at higher gammas to obtain the best color saturation (see fig. 11).

Cibachrome is a material on which it is possible to reproduce density slices in many different colors on a single sheet (see fig. 11A). This is one case in which it is best to print the slices, reversal images made from the increment-complement combinations, on 2575 High Speed Duplicating Film. The unexposed Cibachrome material is placed on the register pins in the printing platen, and each of the density slices is positioned on the pins, exposed with a color filter, removed, and replaced by the next in the series, to be exposed with a different filter; and so on. The different filters may be selected from the Wratten series because of their repeatable characteristics; but the dyed acetate filters used in theatrical lighting may be even more convenient, as exposure time with each are short and more nearly the same; and a wide range of colors is available.

Cibachrome materials are made for the reproduction of the dyes in color film photographic transparencies, and have built-in compensations for correcting between the differences in the color film dyes and those in the Cibachrome. Where any filter is used, some experimentation may be necessary to get the right exposure time for recording the filter color on the Cibachrome. Each batch of Cibachrome manufactured also includes recommendations for inserting color correction (CC) filters between the light source and the image to be exposed, to ensure a standardized color

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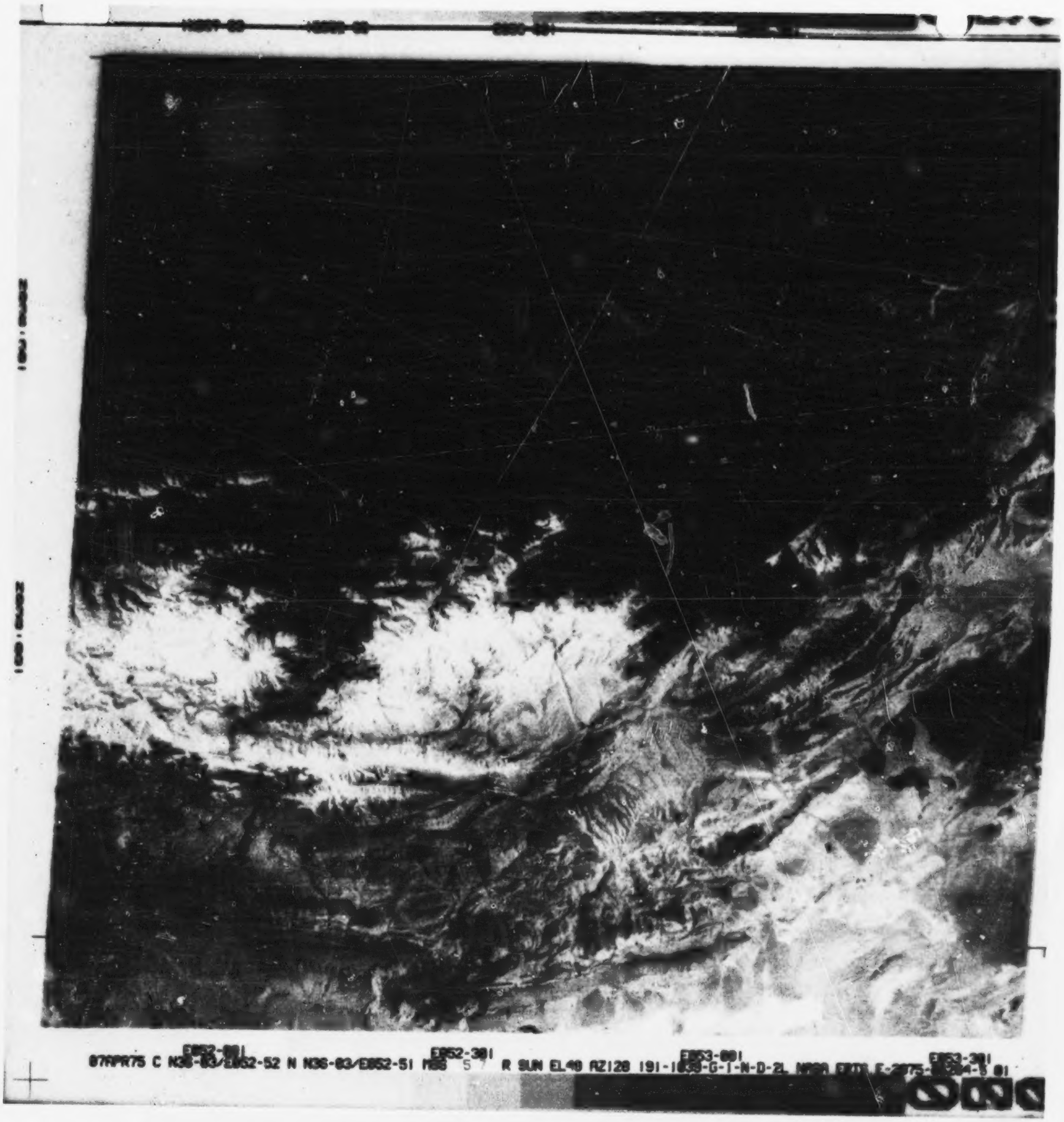

Figure 11. CIBACHROME print made by sequential exposure of pre-registered MSS bands 4, 5, 7 to blue, green, red light (page 203). The B/W positives were of increased contrast. An enlarger and theatrical acetate filters provided the exposure source. (Iran, E-2075-06264, 7 Apr 75.)

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FIGURE 11-A. CIBACHROME print of seven density slices made from LANDSAT E-2179-07470-5, central Turkey. See Figures 6 and 9. The lowest reflectances from the scene in this red MSS-5 band are from 0 to 2.5 on the scale, and are deep blue. 2.5 to 3.0 represents the next highest reflectance; 3.0 to 3.5 was not printed and is black, followed by a cyan-colored slice, and so on. The highest reflectances shown are red, above 7.0. The 2.5 - 3.0 slice is illustrated in B/W in Figure 7. Theatrical acetate filters were used, with an enlarger as a light source, in making this print, as described on page 203.

balance by compensating for manufacturing differences. Although the enlarger is used only as a light source, the CC filters suggested for only one of the film types (Kodachrome, Agfacolor, etc.) should be used to ensure repeatable results.

Dupont Cromalin offers another way to display color density slices, either on reflective paper prints, or as transparencies on transparent materials. Positive and negative processes are also available. With Cromalin materials, a UV exposure source, vacuum frame, and laminating console are required. As positive and negative, reflective prints and transparency options are available, printing procedures differ; but the basic principle is that exposure to a UV source activates the material to permit microscopic particles of powder to adhere only where the image has been exposed. By a series of exposures, and dusting with powders of different colors, a multicolored, or color-coded series of density slices can be reproduced.

A sample of this procedure, produced by Integrated Satellite Information Systems, Limited (ISIS Ltd.) Prince Albert, Canada, is illustrated in figure 13.

Many cartographic and map reproduction agencies are equipped to make Cromalin prints.

Visual Color Display

At this point, it is necessary to insert a few cautions. The eye can detect millions of color differences, under ideal laboratory conditions. But, in real life, either when examining the additive color viewer screen, or a color print or transparency, the ability of the eye to perceive significant color differences is much more limited. There are many factors that condition visual response. Among these are the color itself (it is easier to detect changes in some colors than in others), the size and shape of the colored area, its background of other colors, the intensity of illumination and, not least, the physical and psychological conditions of the observer. Many non-colorblind people have slightly different abilities to perceive color, under the best conditions.

The range of colors in a display should, therefore, be as strictly limited as the requirement to separate significant data will permit, and these colors should contrast as strongly as possible. This probably limits the useful range to about 10 or 12 hues. Many workers favor displaying colors in the natural spectral order; e.g., blue, blue-green, green, through to yellow, orange, light red, dark red. In practice, this often makes it difficult to determine where yellow in the image changes to orange, or blue to blue-green, especially when the colored areas become very small. Small areas of the same color, widely separated in the image, and against different color backgrounds can appear

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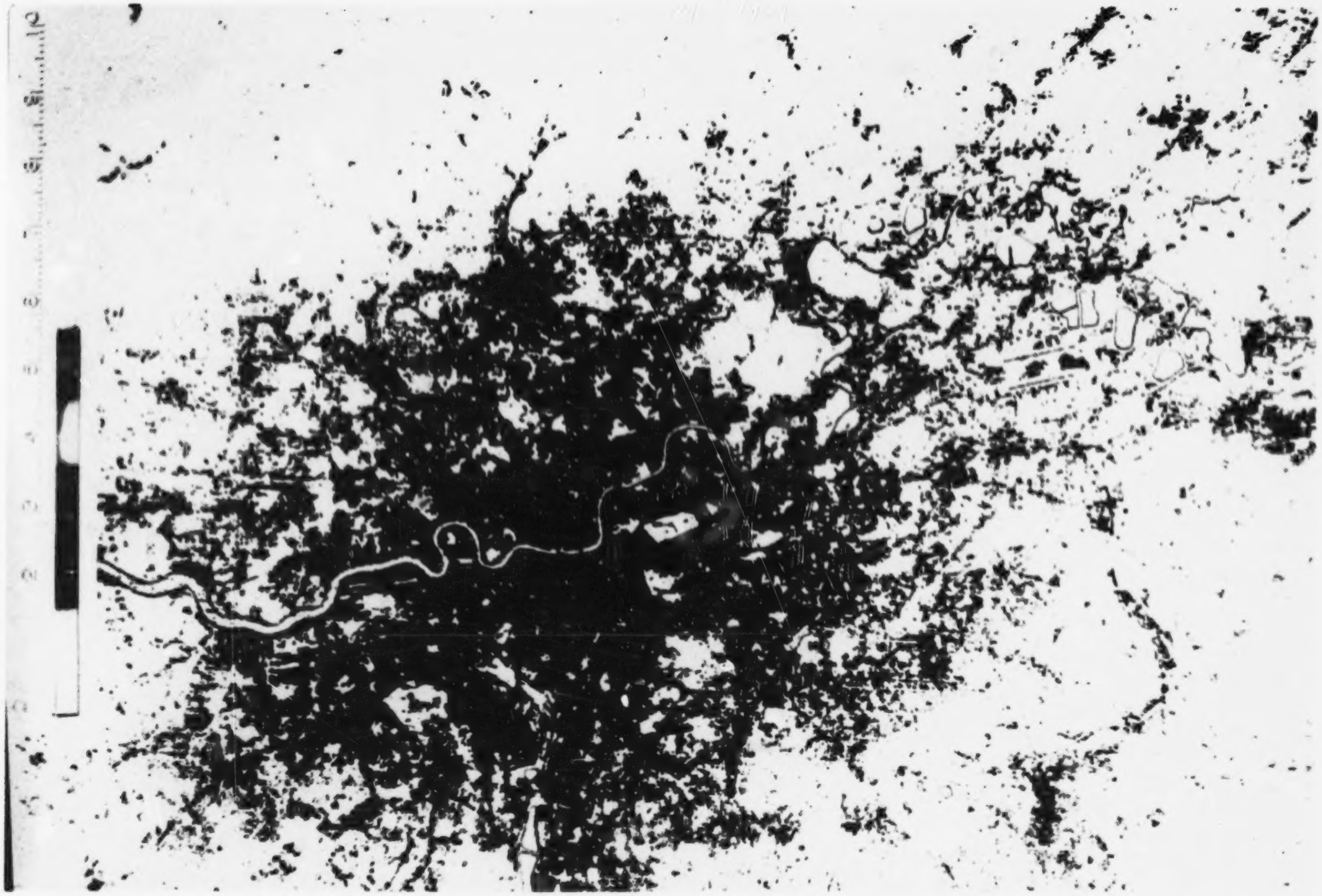

FIGURE 12. Four slices from a LANDSAT image of London, England have been printed in the above by the Dupont CROMALIN process, used by many map production agencies. CROMALIN is one of the excellent alternative methods of reproducing density slices in color on a single sheet. (35 mm Kodachrome enlargement. CROMALIN print courtesy ISIS Ltd., Prince Albert, Saskatchewan, Canada.)

to be quite different. It is much better visually to make adjacent density slices of strongly opposing colors--red next to green, or blue; blue next to yellow or orange; orange next to brown; and so forth. What order and colors are selected depends on several factors: the range of color hues and their saturation available in the reproduction materials at have, and the necessity to display as clearly as possible the smallest changes in the spectral reflectances of the subject under study.

As a rule-of-thumb, it is probably best to have the dark but contrasting colors represent the lowest reflectances in the scene: black, dark blue, dark green. In the more highly reflective parts, the highest may be left white, the next lowest, orange, magenta, brown, olive, etc. But if the objective is to emphasize differences between the lowest scene reflectances, the brighter colors, the yellows, reds, light greens, can be used. For maximum emphasis of important density contours, a highly saturated red appears to stand out from the image in relief, especially when adjacent slices are in the darker hues.

The selection of colors and their sequences for conveying information has been the subject of research and debate among cartographers and map reproducers for many years. it must be admitted that this area still owes more to the arts and crafts than to science, and color selection depends much on the priority the reproduction gives to different kinds of information.

For future improvements, we should investigate more thoroughly what the cartographers have already explored, and pay some attention to psycho-visual research. Where extraction of information is the objective, an artistically very pleasing color rendition of a subject often may be improved greatly by using garish, clashing colors.

Sensitometry for Photo Enhancement Control

Sensitometric control over image enhancement processes is essential. The image interpreter, who is the final arbiter of image content, may not be familiar with this subject, and a few words are warranted. To oversimplify the definition of sensitometry: it is the measurement and interpretation of the response of photosensitive materials, in terms of density and gamma, against a series of known, increasing exposures, under given processing conditions. Gamma is determined from the densities which result. The definitions of density and gamma were given earlier.

Two things are needed to have sensitometric control adequate for most photoreproduction and enhancement processes: A means of making a controlled esposure series where exposure is the product of radiant flux intensity, and time; and a way to measure density.

For controlling flux in the exposure series, a 21-step gray scale is normally used. Steps increase in 0.15 density units, from a nominal 0.05 D to 3.0 D plus. Each step represents a 50 percent change in transmission, or exposure to radiant flux. Moderately priced sensitometers use tablets of this kind to modulate the exposure series, and contain light sources having constant illumination for predetermined exposure times. Such sensitometers make it possible to compare, under similar conditions, the characteristics of different photo materials with one another, and the effects of different processing conditions.

The majority of sensitometric control operations can be conducted with the step tablet* only if it is included with the image being printed, on the same sheet of film, is exposed for the same time to the printing light, and is processed as an integral part of the image being reproduced. The slope of the response curve plotted from the tablet printed with the image then shows the gamma at this stage of reproduction. If the scene contrast in a Landsat image is assumed to be $\gamma 1.0$, the print made from it will have a new scene contrast equivalent to the new gamma. Moreover, densities of subjects of interest in the original scene, the image being printed, can be related to those in the reprinted image; and their positions on the reproduction curve can be ascertained, even if they fall on a non-linear part. The densities in the input image will control those in the print, as shown in figure 13; and so may be traced into their new positions, and the increase in gamma calculated.

The means of reading transmission density values may vary from those of electronic instruments with digital display to those in which the density being read is visually matched in a comparison field. Electronic densitometers are recommended as the better investment for enhancement work, as they read densities up to 4.0 (i.e., 0.01 percent transmission) and are repeatable to ± 0.02 D.

The measured densities, when plotted against the exposure scale (the step tablet densities which modulated the exposure into the reproduction), define (outline) the slope (gradient) of the film response curve from which the gamma can be found, as described earlier.

The film response curve has other uses in addition to ensuring that the exposure-processing cycle has produced the desired gamma. Changes in the shape and position of the curve in successive exposures with the same emulsion can reveal deterioration in the developer, aging or voltage drop in the exposing light, or changes in the emulsion brought on by age or poor storage conditions. But the main use of the curve in image enhancement processes is to establish an understanding and verification of the characteristics of the photo materials on which enhanced images are to be prepared. As an example, if an MSS image has

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* Densities in the step tablet printed on Landsat images are related to a linear progression of sensor voltage counts, and are generally inadequate for normal photoprocessing control.

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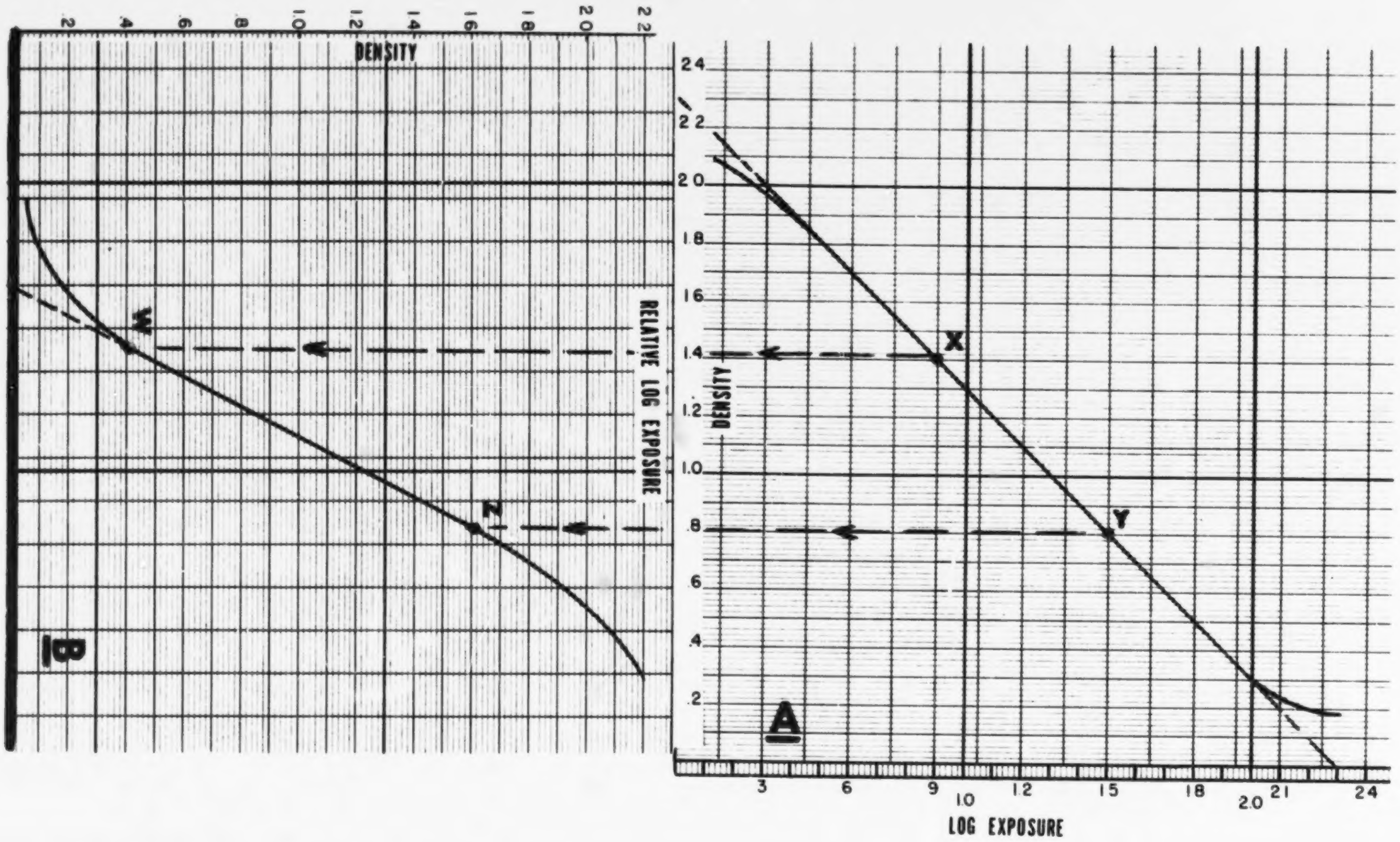

FIGURE 13. In the graph A, above, the characteristic curve of a positive image has been plotted. The measured densities of two areas of interest in the scene are plotted at x and y. It is desired to reproduce the image at a higher contrast, without distorting the linear relationship of the scene densities between x and y. The positive is printed to a negative, the curve of which is plotted at B. (Note that the positive densities become the log exposure scale for the negative.) By measurement it is found that w and z are now the densities of x and y in the negative, and are on a linear part of the curve. Calculate the gammas of A and B (page 209). What is the reproduction gamma of B?

subjects which include a density range of 1.0 D, from 0.6 D to 1.6 D and it is desired to increase image contrast in this range by a factor of 2x--that is, reproduce it at 2.0--without further distortion of this 1.0 D range, a material must be found in which the image can be printed on a straight-line part of its response curve that has a range of 2.0 D.

Assume now that an emulsion is identified which meets this requirement, but it is noted that its straight-line response begins at 0.9 D, and ends around 3.0 D; a density range of 2.1, at gamma 2. To insure linear production in printing, exposure must be such that the 1.6 D in the MSS image is reproduced around 0.9 D in the new emulsion, and the MSS 0.6 D around 3.0 D.

The characteristic responses of various emulsions, as exposed and processed under given photo laboratory conditions, can be found by exposing a step tablet for a series of different times on the material to be tested. These exposed films can also be processed for different times in different developers, to find the time of development which will yield a desired gamma.

These measures are adequate for controlling limited production and manual processing. Where large-scale operations and machine processing are involved, more stringent control and statistical sensitometric analyses should be adopted.

SUMMARY

The Landsat satellites were intended only to be experimental forerunners to establish specifications for effective operational systems to come. In their brief lives, they have more than fulfilled their role, and although still experimental, operational applications are already in train.

One facet has been shown very clearly: the ability to analyze the huge amounts of data the imaging satellites can collect far exceeds the capability of present machine technology to reduce it in a timely manner into usable information, for many earth science subjects. While this problem is being addressed vigorously in the development of appropriate computers and machines, it is likely that there will always be a need for image analysis by humans, interpreters skilled in earth science specialties, who will prove to be more cost-effective than machines for certain analytical tasks.

There are those who hold that while the brain may function by a series of digital, electrical nerve impulses, the deeper thought processes are conducted by analog processing, where large amounts of data stored in the memory under many different categories can be reviewed simultaneously, in parallel. The analog process permits dismissing, without further thought, memory data which are not applicable while seizing on those data which are pertinent.

However, if data in the image are not recognizable to the eye, no path to the memory can be stimulated. Since visual photointerpretation is likely to remain an important method for the rapid and timely analysis of earth resources information for a long time to come, it is worthwhile to develop and adopt image-enhancement methods which best serve the needs of the earth science disciplines, as a matter of routine production.

This paper has given only an outline of some current photographic techniques, which can and should be improved and supplemented. Nor should it be construed as an argument that photographic image enhancement will solve all interpretation problems. The objective is still to get the most information out of the image, by whatever means technology and human skills can evolve.

AN INVESTIGATION INTO THE RECTIFICATION OF MULTISPECTRAL SCANNER IMAGES

By Colonel M. Sadeghieh, Technical Deputy Director
National Geographic Organization

and

Eng. Rostam Yazdani, Director of Aerial
Triangulation Department
National Cartographic Centre of Iran

ABSTRACT

The National Geographic Organization (NGO) has used false-color Landsat images at a scale of 1:1,000,000 for general information and study, to distinguish forests, rivers, roads, and landforms.

NGO has prepared a controlled photomap of the Ferdows area and an uncontrolled photo map of the Tehran area at the scale of 1:250,000, using 1:1,000,000-scale Landsat multispectral scanner (MSS) images. Villages, rivers, dams, roads, and land form boundaries have been drawn on the photomap, to be utilized for reconnaissance and area identification.

It is hoped that NGO will in the future use MSS imagery for obtaining general information for application in its topographic mapping and field study programs.

INTRODUCTION

Since the launching of the first Earth Resources Technology Satellite, now named Landsat, much MSS data from various parts of the world have become available for the survey of natural resources.

The Landsat multispectral scanner is a line-scanning device which uses an oscillating mirror to continuously scan the terrain beneath the spacecraft. The scanner produces four synchronous images, each in a different wave band. The wave length ranges of each band are:

Band 4 (green) ------------------------ 0.5 to 0.6 micrometers
Band 5 (lower red) -------------------- 9.6 to 0.7 micrometers
Band 6 (upper red - lower infrared)---- 0.7 to 0.8 micrometers
Band 7 (near infrared) ---------------- 0.8 to 1.1 micrometers

CARTOGRAPHIC APPLICATIONS

BY THE NATIONAL GEOGRAPHIC ORGANIZATION

The National Geographic Organization has used--as have other technical organizations of Iran--false-color images for general study to obtain information on forests, mountains, rivers, and landforms.

NGO has prepared a controlled photomap of the Ferdows area and an uncontrolled photomap of the Tehran area at the scale of 1:250,000 by using 1:1,000,000-scale Landsat MSS images. Villages, rivers, dams, roads, and landform boundaries were drawn on the photomap to constitute the first use by NGO of MSS pictures for reconnaissance and area identification.

For the present study, black-and-white positive and negative transparencies of 1:1,000,000-scale Landsat MSS images (bands: 4, 5, 6, 7) were used. A fixed facility for enlargement of four times was used to prepare 1:250,000-scale imaging for initial study, and the four control points that were keyed to mountains and other features observable on both the 1:250,000-scale map and the 1:250,000-scale MSS positive transparencies were chosen for geodetic control. Rectification was done using a SEGV (Zeiss) recitfier and the four control points. Three control points were matched quite well, but a 10 mm discrepancy was found at the fourth point. As there is deformation on the 1:250,000-scale line maps (1° x 1° .30' or 110 km x 110 km), which is caused mostly by the projection system, it may be concluded that rectified MSS imagery would have a scale reasonably comparable to the same scale line map.

NGO produced the photomap of the Ferdows area (fig. 1) in the following pattern: roads in red, water in blue, background in light brown, grids in white and a few sample names in black.

A comparison of rectified MSS imagery at 1:250,000-scale and a line map of 1:250,000-scale shows that reasonable accuracy could be obtained from MSS imagery. However, attempts to identify on the imagery roads and new villages which had not been drawn on the line map were not successful because of the small scale of the imagery.

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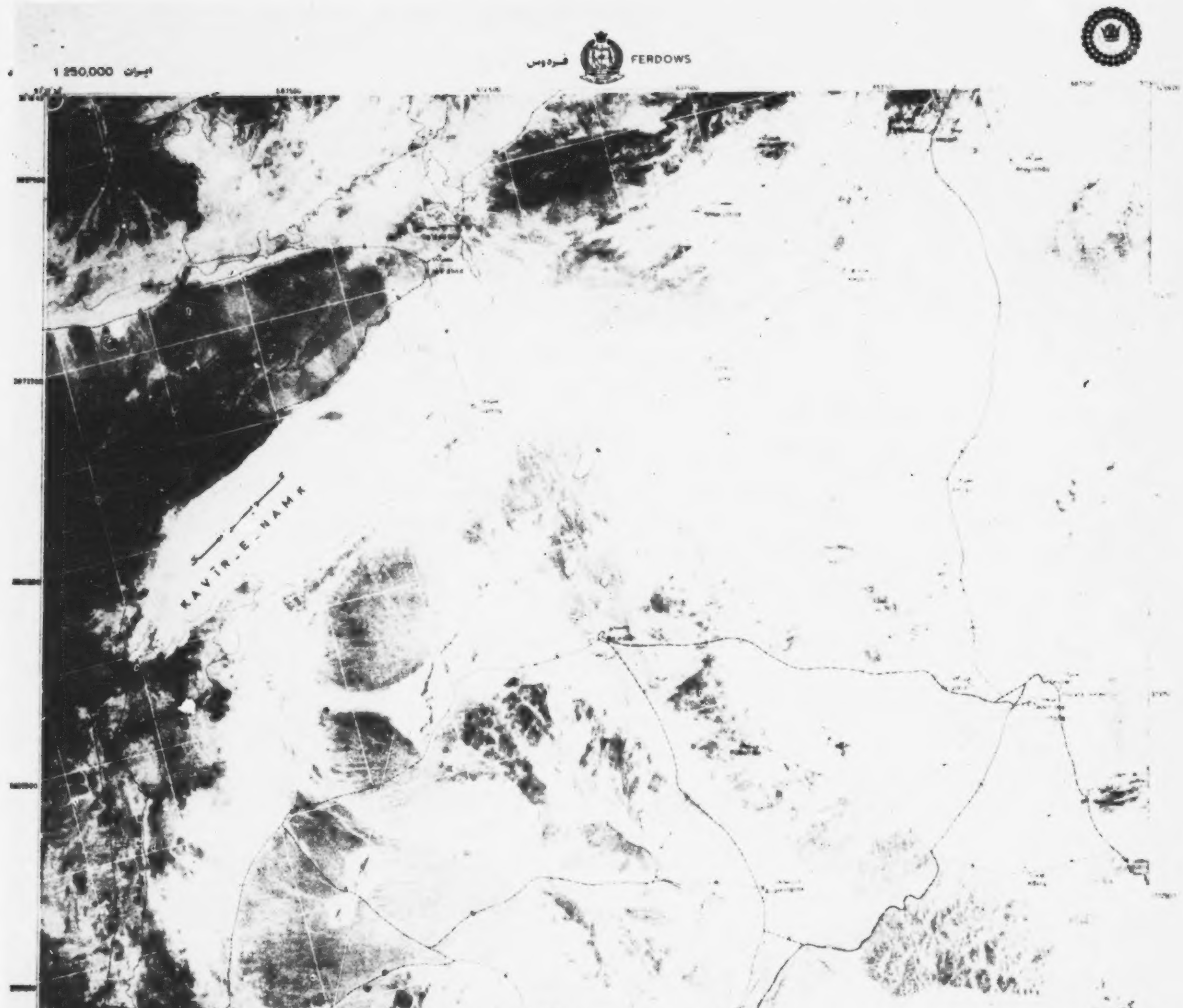

Figure 1. Landsat image map of the Ferdows area, Iran.

MAPPING OF FOREST AREAS BY USE OF LANDSAT IMAGES

By Mehmet Sumer
Forest Mapping Directorate

SUMMARY

Investigation of applications of Landsat (originally ERTS) images by the Forest Mapping Directorate began in 1972. Landsat-2 images of the forest region of Antalya and the lakes were selected, and analyses were made without reference to existing forest maps. A densitometer (Kodak 10.K) was used to examine band 4, 5, 6, and 7 images. Of these, band 5 was found very suitable for forest mapping purposes; and the following relationships between forest classes and band 5 image densities were determined:

Forest class	Density range
Good quality forest	1.40 - 1.86
Second quality forest	1.20 - 1.40
Coppice forest	1.00 - 1.20
Agricultural area (non-forest land)	0.87 - 1.00

Thus, it has been possible to map boundaries and classify types of forest areas, employing the Landsat images and densitometry.

A second area, the İzmir-Aydin region, was selected for additional investigation of Landsat images for forest mapping, employing the following procedure:

1.1 Select a known forest region.
2.1 Select a well-mapped forest area.
3.1 Employ existing forest maps at 1:500,000-scale for comparative analysis.
4.1 Enlarge Landsat images from scale 1:1,000,000, as delivered, to 1:500,000, employing standard photo-laboratory procedures.
5.1 Map the forest area as interpreted from the Landsat images.
6.1 Compare the Landsat analysis of forest types with the previously existing forest maps.

On the basis of results to date of investigations by the Forest Mapping Directorate, it is concluded that Landsat images of good quality are useful for forest mapping. It is considered that color-composite photoimages would be of especial value. It is intended that Landsat data will be employed to the extent possible in the Forest Mapping Directorate, by the most effective methods available.

CORRELATION OF LANDSAT-DERIVED STRUCTURAL DATA AND GEOLOGICAL AND GEOPHYSICAL DATA WITH THE DISTRIBUTION OF KNOWN MINERAL DEPOSITS FOR MINERAL EXPLORATION

By Ural Tumer
Mineral Research and Exploration Institute

INTRODUCTION

The remote sensing unit, established in the Geophysical Department of the Mineral Research and Exploration Institute of Turkey at the end of 1975, has been carrying out various projects, using different remote sensing techniques and devices, based mainly upon Landsat Multispectral Scanner (MSS) images obtained from the EROS Data Center. One objective has been to investigate possible mineral provinces in western and eastern parts of Anatolia. Another has been to update the geological maps at small scales (such as 1:500,000). In addition to these, there are other projects under development to map major fracture and fault zones.

Investigations employing computer-compatible tapes (CCT) are also to be made but, unfortunately, the computer tapes have not arrived in time for work preparatory to this report (CCT's that arrived two days ago are still in Customs). Instead of CCT's, black and white images in positive and negative paper prints and films were used, the films being employed in a density slicer (ISI-VP8 image analyzer) and a color-additive viewer (I^2S-PT6040). In addition, a drainage pattern map has been prepared photographically in our photographic laboratories by using band 7 in positive and band 5 in negative. Our work with the CCT's will be performed on a PDP 11/45.

APPLICATIONS IN MINERAL EXPLORATION

This investigation is a continuation, or an extension, of a previous one. The attempt was made, in the first stage, to prepare a series of detailed geologic and tectonic maps at 1:500,000 and 1:250,000 scales; the second stage attempts to make a correlation between structural data and the distribution of known mineral deposits. For the prediction of possible or probable mineral zones, we are concentrating on fault zones and geological contact zones. Consequently, by marking the known mineral localities on these images, it will be easier to see possible continuations of them and, if criteria for recognition of their associated mineralization zones can be established, it may be possible also to detect new areas by comparison. For this reason, interpretation of the images was done by starting from a known geological structure for a small area on each image, then the surrounding area was investigated, employing the image analyzer.

The interpretation of remote sensing data is dependent not only on the experience and knowledge of the scientists who are involved in remote sensing, but it is dependent on the instrumentation as well. The really significant thing about instruments is not that they allow a scientist to do a given job in shorter time, but that they can also allow a scientist to produce much more in a given time.

For the data enhancement, all the data that we have has been used, including 70 mm and 230 mm positive and negative transparencies, and paper prints. The imagery was enlarged photographically from 1:1,000,000 scale to 1:500,000 and 1:250,000 scales, and in some certain cases to 1:125,000. The last has not given good results, because of the prominence of scan lines at such a scale.

All findings have been compared with existing geological and geophysical data, and field investigations have been carried out at 125 points during a two-month period.

Let's have a look, scene by scene, at the investigation area (index map, fig. 1).

The first scene (figs. 2, 2a, 2b) is of the Kapidagi Peninsula region. Approximately 30 percent of it is covered by the Sea of Marmara. There are three big lakes in the region, Iznik, Apolyont, and Manyas. Manyas and Apolyont lakes are shallower than Iznik, and Manyas is shallower than Apolyont Lake. The first two lakes are seen

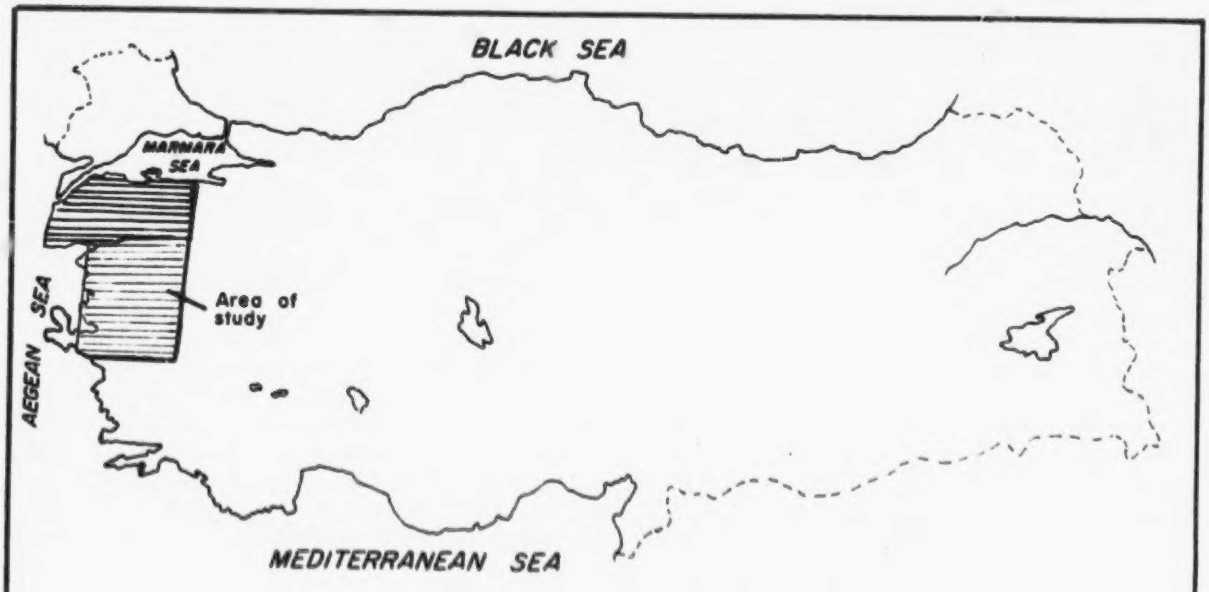

Figure 1. Index map of Turkey showing area of study.

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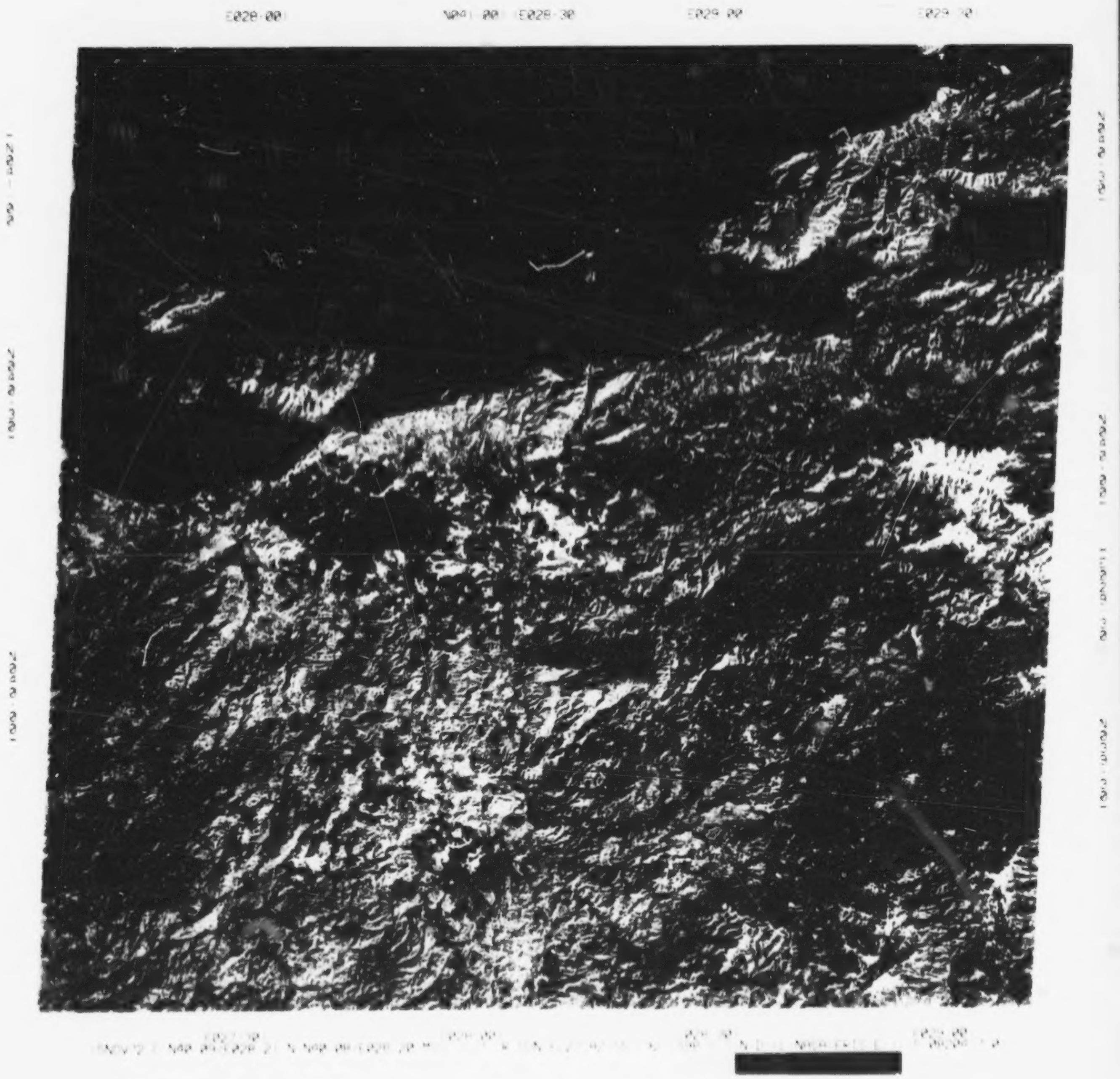

Figure 2. Kapidagi Peninsula Region (Landsat MSS band 5, November 15, 1971).

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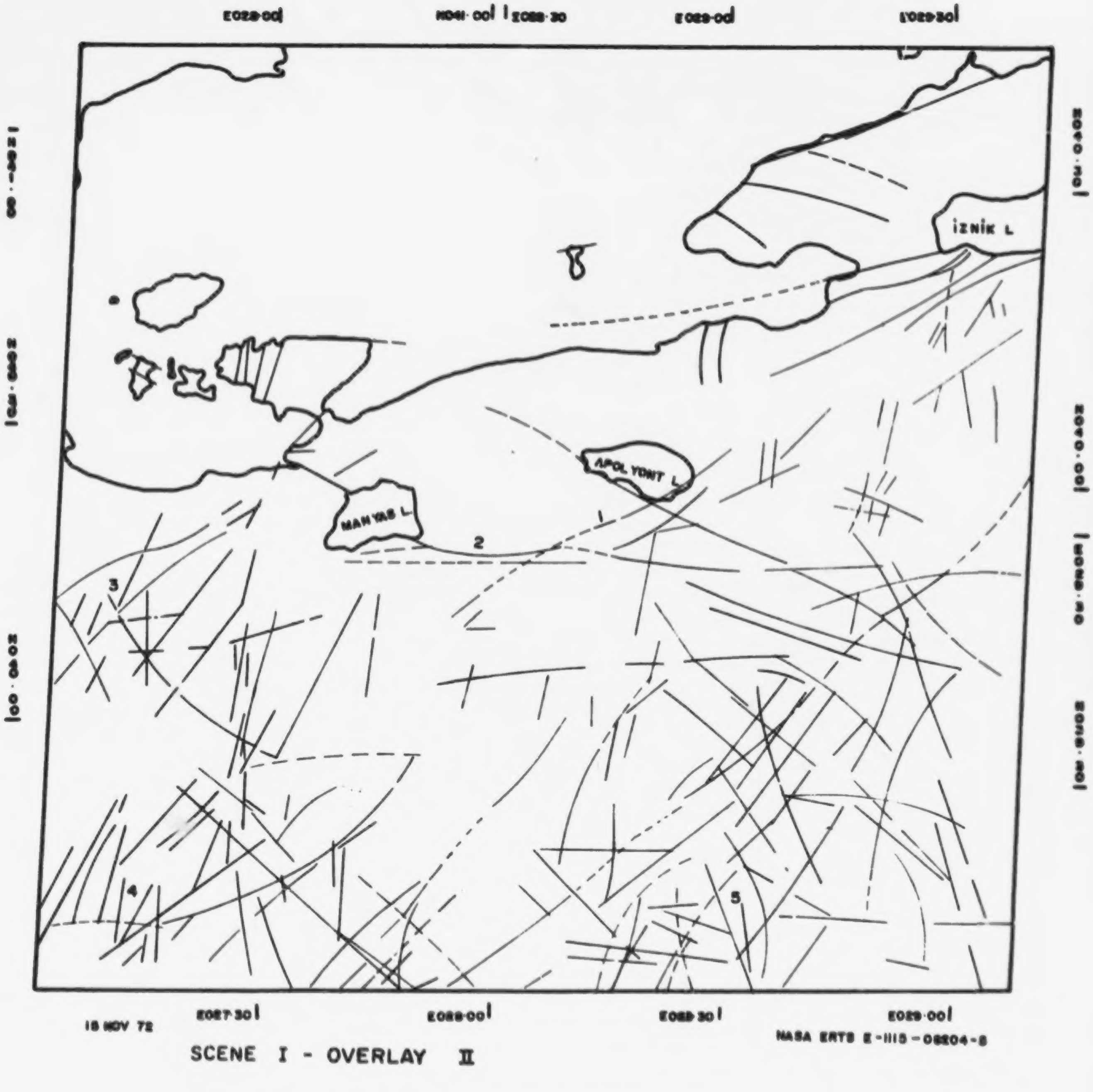

Figure 2a. Overlay for figure 2; lineaments detected in Landsat image of Kapidagi Peninsula Region, Turkey.

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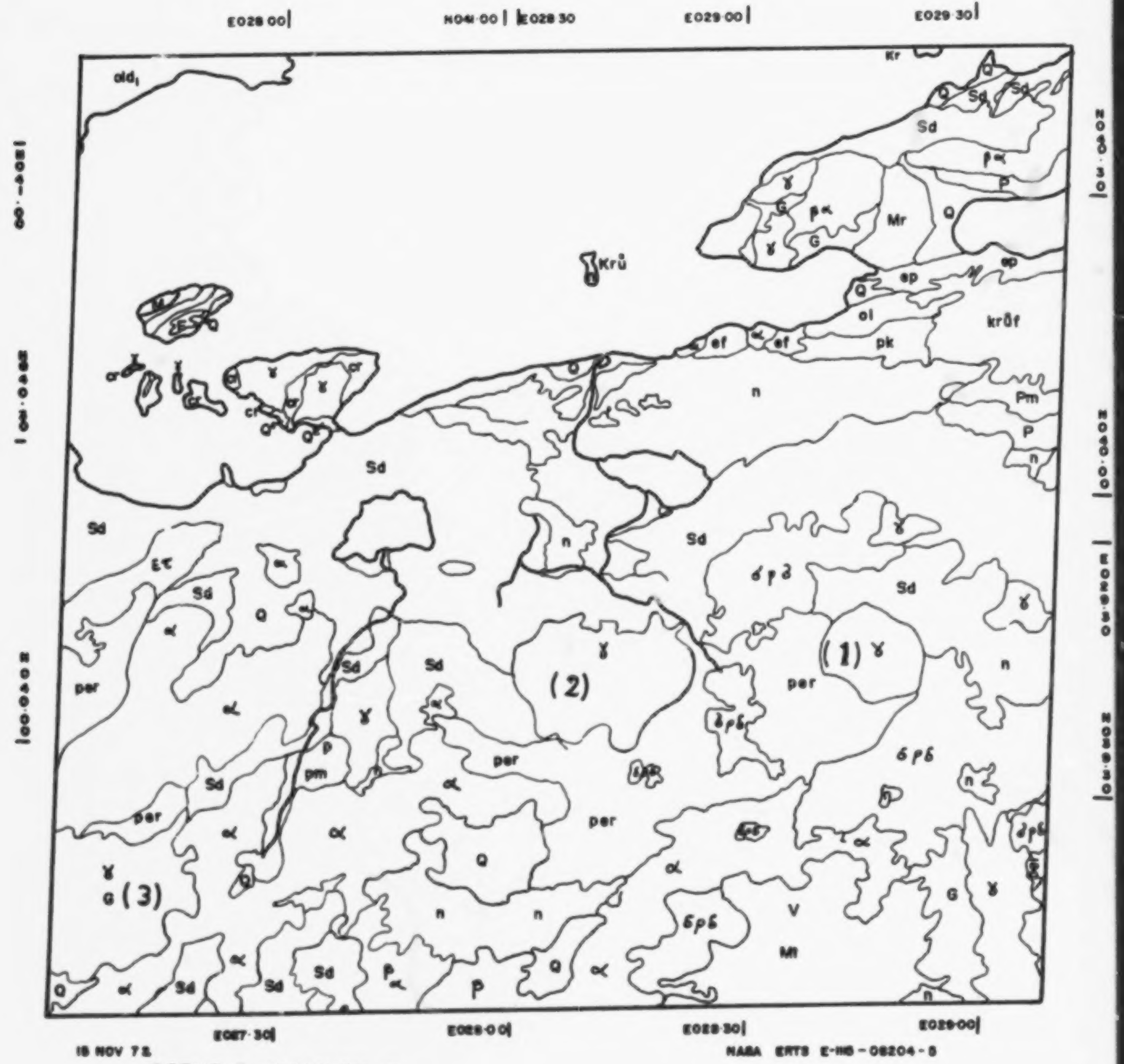

Figure 2b. Overlay for figure 2; geologic formation boundaries in region of Kapidagi Peninsula, Turkey.

as light grey in black and white imagery, and it is difficult to discriminate which is clearer than the other. But when we look at the color composites (fig. 3), evidence of pollution by flood water entering Apolyont Lake is obvious. Sedimentation zones and stream discharge zones on the southern shores of the two lakes can be easily seen. Changes of the shore lines of these two lakes by sedimentation in a period of 10 years can be seen by comparing an old map and the imagery.

Color changes of all lakes and rivers in the region seen on the images can be caused by water pollution or flood water.

A fault, marked 1 in figure 2a, passes in a northeast-southwest direction near the southern shore of Apolyont Lake which is situated in a "V" formed where this fault crosses another one. Fault 2 passes through the Manyas Lake in a northwest-southeast direction, turns eastward and cuts fault 1, then continues in an easterly direction. Numbers 3, 4, and 5 mark large fault groups in the region.

The geological formation boundaries are shown in figure 2b. The southern and western Bursa region is generally covered by andesite; but also prominent are three granite massifs, numbered 1, 2, and 3. Comparison of the image and the geological map reveals a difference in the representations of the granite boundaries. Such variances are clearly detected in southern Bursa and the Kapidag Peninsula.

Finally, when the known mineralization zones and the locations of mines in the region have been marked, it is hoped that new mineral and mine exploration provinces can be determined.

It is disappointing that the Samli Iron mine, which is an open pit about 800 by 400 meters, and which, with inclusion of the dumping area, covers an area approximately 1.5 km by 7.50 km, is not seen or recognizable on black and white images of the four bands. Consequently, a continuation of its province cannot be predicted on black and white images. The situation is the same for the Eymir Iron mine. The location of the mine pit can be detected only by the recognition of its straight border of pine trees. However, it is believed that some promising areas for further geological surveys for minerals might be determined by using some more sophisticated devices and very good quality color composites.

The second scene (figs. 4, 4a, 4b) shows the Izmir region, which adjoins the Bursa region to the north and is bounded by the Aegean Sea on the west. This region is important for hydrothermal energy sources, mineralization, and earthquake activity which is generated on the fault zones.

A large river, the Gediz, flows from east to west through the middle of the region. A lake, situated in this river valley, is seen to have undergone a change in its shoreline configuration as a result of sedimentation that took place between the time of preparation of the geological map and that of the image.

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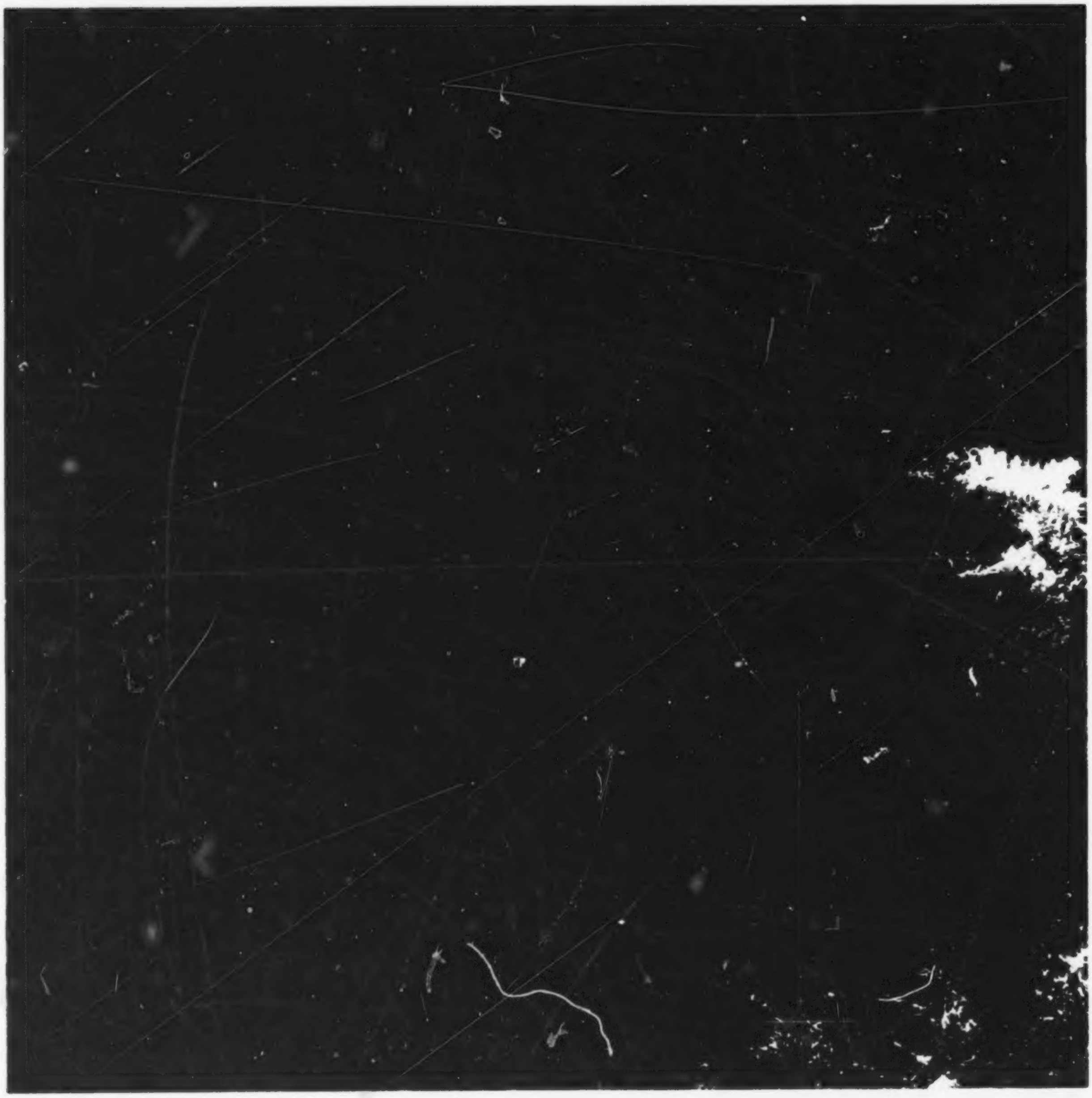

Figure 3. Standard false-color composite (Band 4- blue; Band 5- green; Band 7- red) from screen of color additive viewer. Shows relatively clear surface water of Marmara Sea in black, water bearing suspended matter at surface of Lakes Apolyont and Manyas, in light blue tones.

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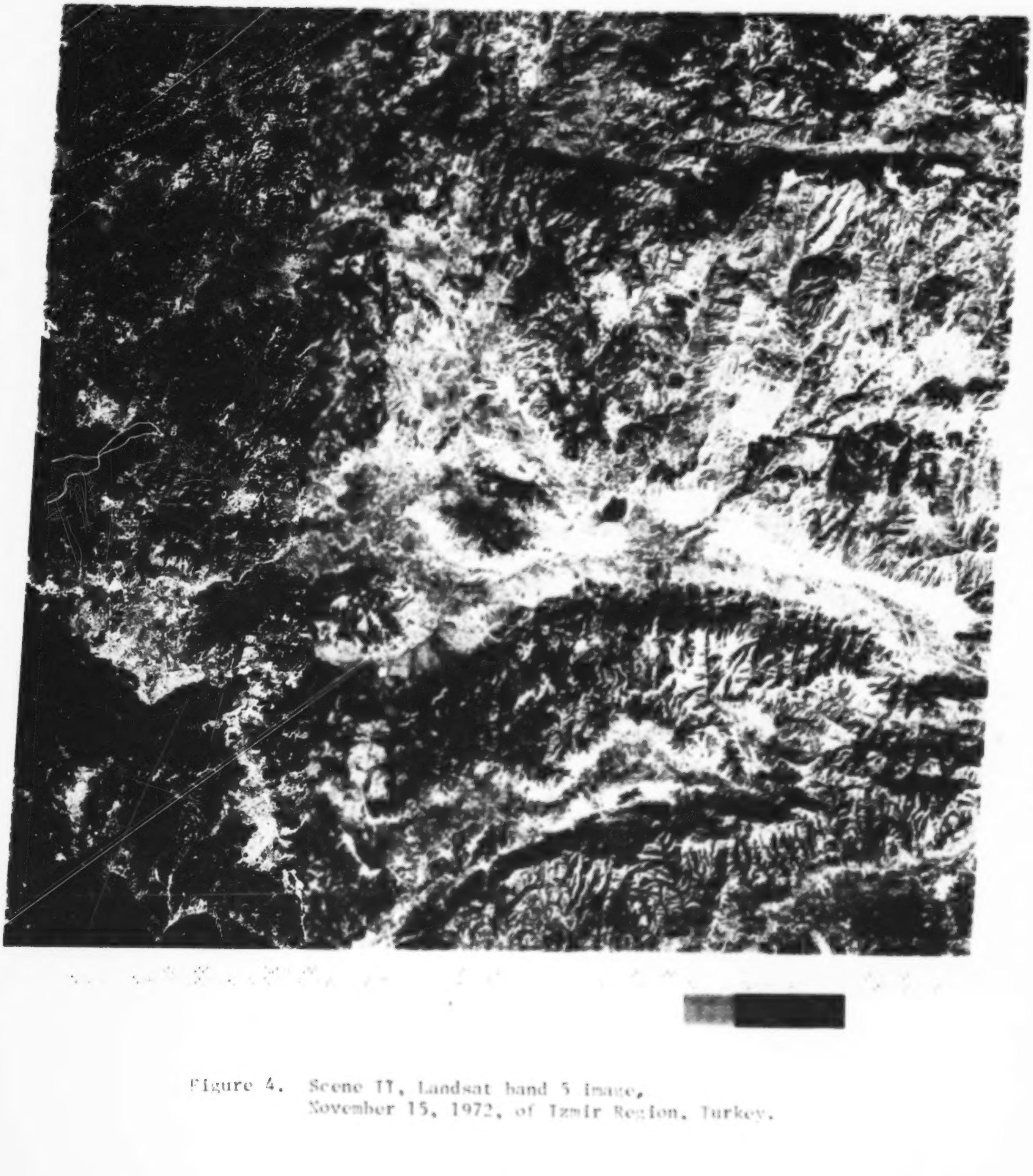

Figure 4. Scene II, Landsat band 5 image,
November 15, 1972, of Izmir Region, Turkey.

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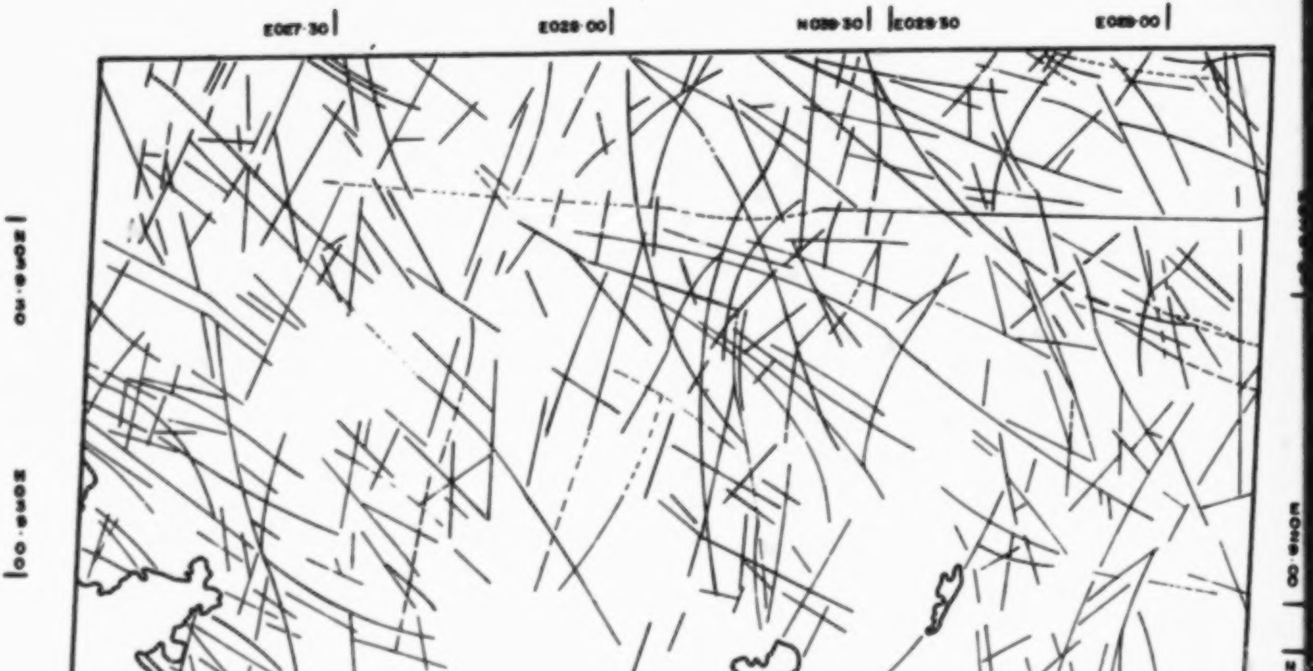

Figure 4a. Overlay for figure 4; lineations detected in Landsat image of region of Izmir, Turkey.

Demirkopru Dam is situated across a fault valley, as is a common situation in Turkey, where 95 percent of the dams are located in inactive fault valleys. A basaltic zone, volcanic cones, and craters are seen to the east of the Demirkopru reservoir, in an area that measures 10 by 14 km. In addition, there are basaltic tuffas in the middle of the zone. With their black color on the band 5 image, they look like the lake of Demirkopru. However, the basaltic tuffas were differentiated from the lake by density slicing. There is on this frame another small lake, the true nature of which could also be determined by density slicing.

Determination of geological structures and formation boundaries was easily made when the imagery was compared with the geological map; some variances were seen. The shape of a granite massif that is in the north-west of this scene, again, shows some variance with its shape on the geologic map. This massif is surrounded by andesite and the contact zone is important for iron mineralization. In another case, the boundary of a metamorphic series is an important locus for gold, mercury, and lead minerals. This metamorphic series can be identified easily by the drainage pattern and color. In addition to all this, I would say that the level and extent of pollution in Izmir Bay is very obvious in the density slicing product.

The third scene (figs. 5, 5a, 5b) is of the Biga Peninsula region This region is one of the most important mineralized areas, especially for zinc and lead. Here, geological formation boundaries can be differentiated by the patterns of their drainage systems and color density differences. A large part of this area is covered by forests, which explains why most of the geological formations can only be determined by the patterns of drainage systems. On the west part of the scene (fig. 5b), which is covered mainly by andesites, a great granite massif is seen clearly.

The fault zones in this region trend in two main directions (fig. 5a). These are southwest-northeast and northwest-southeast. It is probable that some faults of the southwest-northeast trending set continue in the Aegean Sea bottom. Some known lead-zinc deposits coincide with or occur very near the intersections of members of these two fault sets.

Finally, after determining geological formations and tectonic lines, one can extend known mineralization zones on the image; metallogenic provinces can be depicted, and their continuations and probable trends can be hypothesized.

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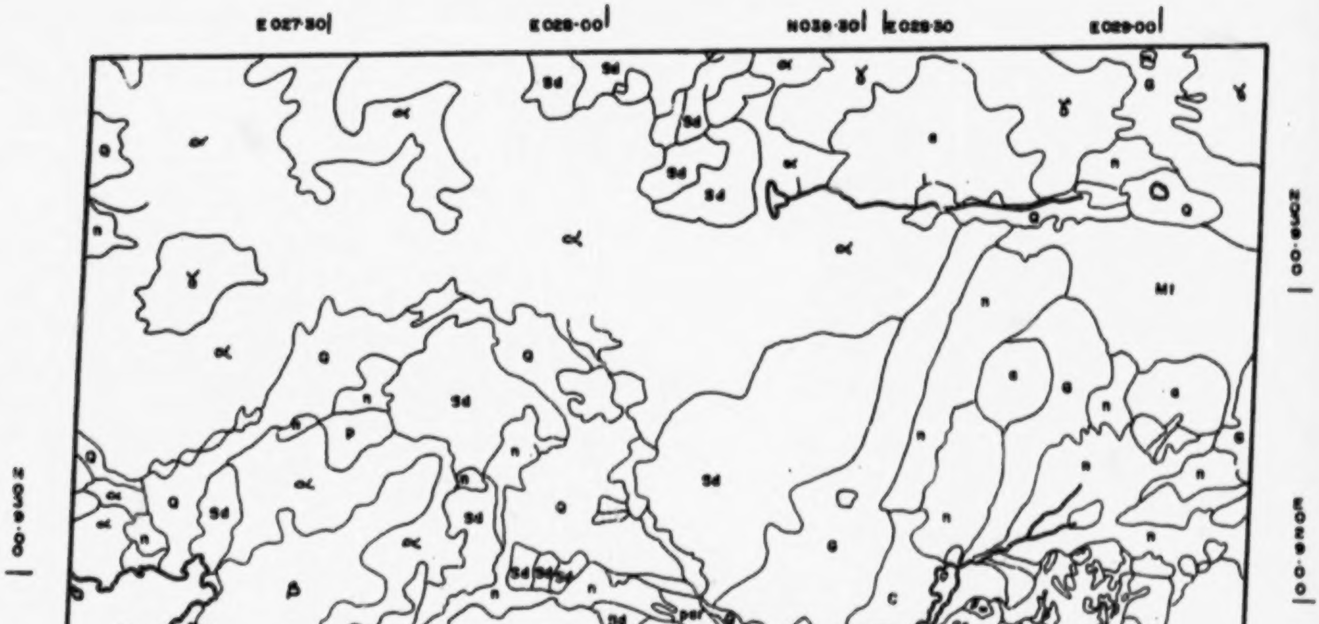

SCENE II - OVERLAY I

Figure 4b. Overlay for figure 4; geologic formation boundaries in region of Izmir, Turkey.

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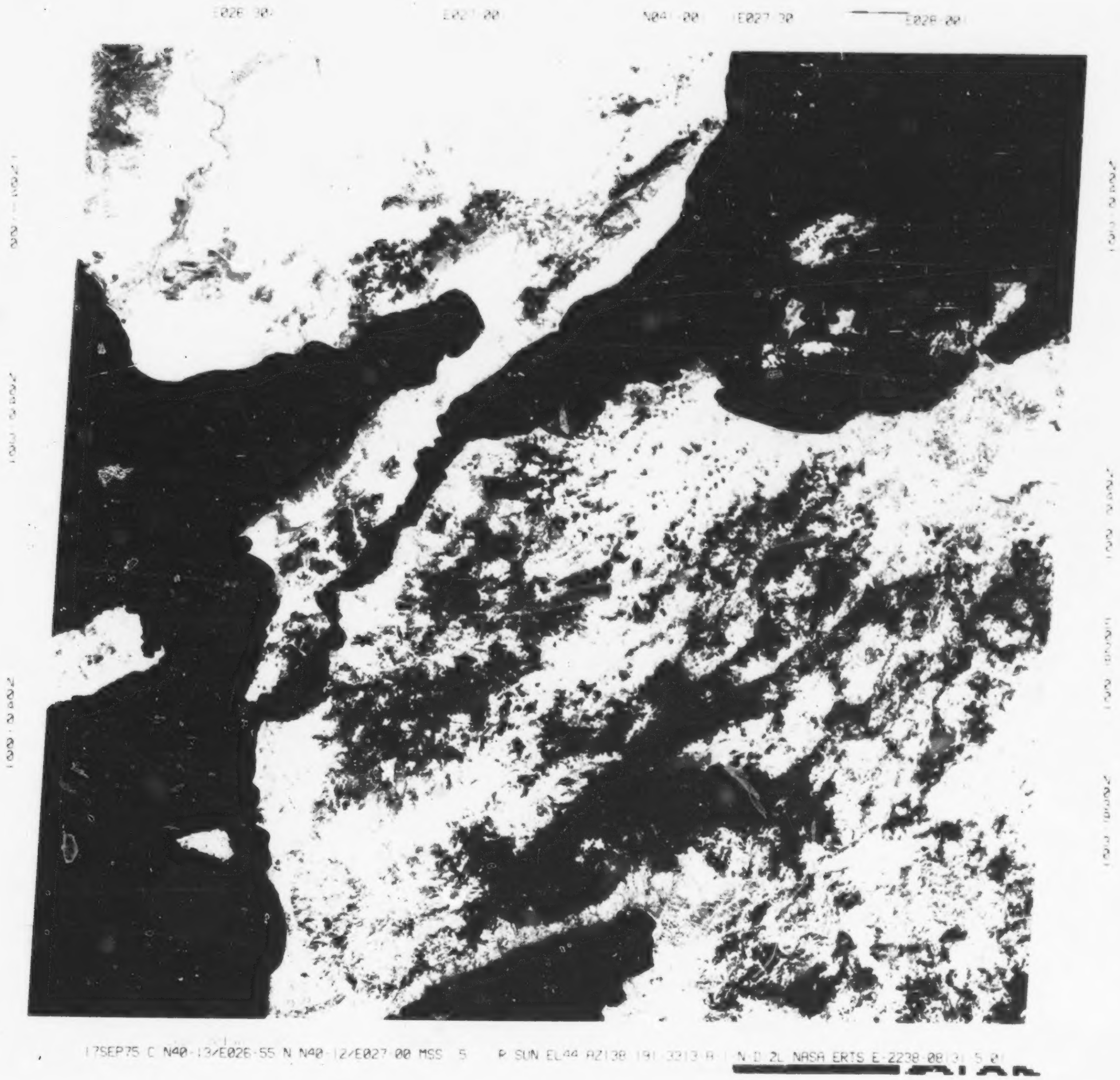
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Figure 5. Scene III, Landsat band 5 image,
September 17, 1975, of Biga Region, Turkey.

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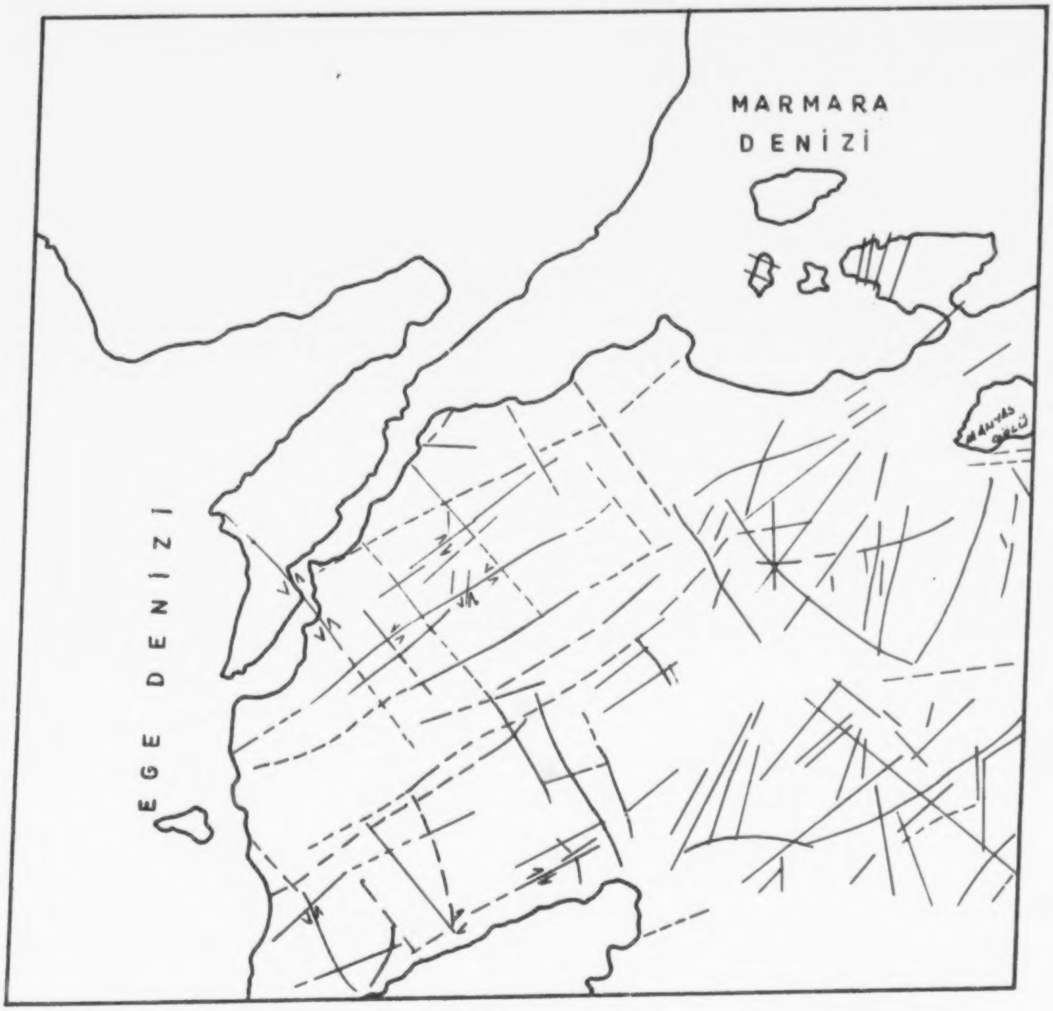

Figure 5a. Overlay for figure 5; lineations detected in Landsat image of Biga Region, Turkey.

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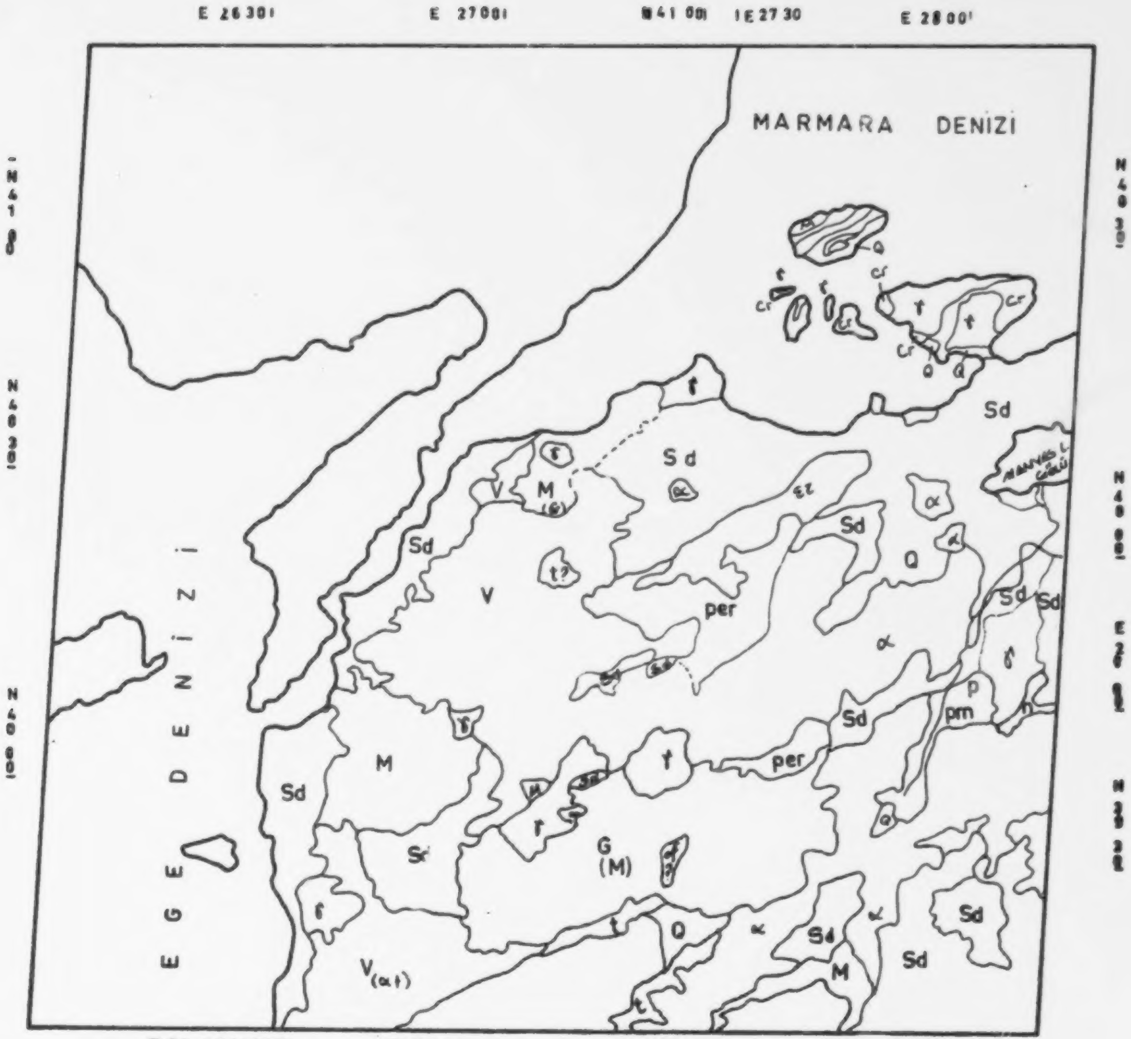

Figure 5b. Overlay for figure 5; geologic formation boundaries in region of Biga, Turkey.

CONCLUSIONS

The following observations may be cited as findings of this investigation:

a) Landsat images are very useful and helpful for reconnaissance surveys, especially for the study of fracture zones and great tectonic trends.

b) Landsat imagery makes the search for some geological zones suitable for mineralization very easy and time saving.

c) The findings that were extracted from images by using simple tools and photographic methods gave encouraging results. If more sophisticated instruments and techniques are used, more detailed information and more satisfactory results, especially on the subject of mineralization, will be obtained for this region.

At last, I would like to thank Dr. Deutsch, who gave me some very interesting and precious slides.

APPLICATION OF REMOTE SENSING IN MAPPING

By Ercan Tura and
Ozcan Ertung

At the seminar held in 1975 at Lahore on "Applications of Remote Sensing Data and Methods," a report was presented on "Applications of Remote Sensing in Mapping" in Turkey; this included information about the interpretation of Landsat-1 images in 4 bands in color composite and black and white, and at the scales of 1:200,000, 1:250,000, 1:800,000, and 1:1,000,000. That work dealt specifically with the Izmir area. It discussed the cartographic findings based on Landsat-1 images and compared them with information shown on topographic maps of western Anatolia.

Because the images necessary to further the research on the same area had not been obtained before the CENTO Istanbul Workshop, the project development and the interpretation that would augment the previous findings will have to wait until the mecessary images are obtained.

In the meantime, even though it has not been possible to carry out new research on the Landsat images, aerial photographs obtained by flights over Turkey have been used by various institutions in the investigation of applications of remote sensing.

Among these have been aerial photographs at varied scales, generally taken by aerial cameras such as the Wild RC-10 and Zeiss RMK-A. These photographs have been widely utilized in the following activities:

a. In producing various scale maps through photogrammetric techniques, the widest and the most highly developed of the remote sensing techniques.
b. In forestry, for detecting the types and ages of trees.
c. In hydrogeological studies, in ground-water studies.
d. In investigating faults in Turkey, specifically the Northern Anatolia fault.
e. In research projects for city planning and urban development.

Another remote sensing activity applied here for the first time in Turkey is the interpretation of the imagery obtained on the Aerochrome Infrared (false-color) film.

The images taken by a Wild RC-10 aerial camera are being used in a special research project to investigate the effects of pollution on trees in a wooded area.

In an earlier examination done without optical equipment, the following have been achieved:

a. Tree types have been easily identified on the false-color films.
b. Bordering plants that are weakened by pollution caused by a factory in the vicinity can be recognized.
c. The scope of land pollution in a vicinity has been investigated.

In addition to normal aerial cameras, a multispectral camera (I^2S, model 10) was used to obtain aerial photography at varied scales in order to permit more detailed work employing the color-additive viewing technique. Kodak Infrared Aerographic film 2424 has been used and was developed in special chemical solutions to obtain best possible results. Detailed research of these images based on the use of a color-additive viewer has been carried out by various institutions in terms of their special needs.

In Turkey, as is understood from this short explanation, activities utilizing the remote sensing techniques are gradually spreading into various fields. The CENTO Workshops contribute greatly to the development of the application of the remote sensing techniques. We thank all parties for their help in this.

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